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THESIS

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THESIS

DEVELOPMENT OF NATOPS PERFORMANCE SOFTWARE FOR THE SH-3D AND SH-3H HELICOPTERS

by

John Thomas Curtis

March 1985

Thesis Advisor: Donald M. Layton

Approved for public release; distribution unlimited.

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This thesis generates closed form equations for significant and frequently used NATOPS performance charts for the SH-3D and SH-3H helicopters. These equations are developed into interactive software for the Hewlett-Packard HP-41CV hand-held programmable calculator. With this software installed in the calculator the user is able to calculate numerous NATOPS performance parameters (expeditiously, with reduced risk of error) both prior to and in flight.

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Development of NATOPS Performance Software for the SH-3D and SH-3H Helicopters

by

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Submitted in partial fulfillment of the
requirements for the degree of

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This thesis generates closed form equations for significant and frequently used NATOPS performance charts for the SH-3D and SH-3H helicopters. These equations are developed into interactive software for the Hewlett-Packard HP-41CV hand-held programmable calculator. With this software installed in the calculator the user is able to calculate numerous NATOPS performance parameters (expeditiously, with reduced risk of error) both prior to and in flight.

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I. INTRODUCTION

A. COORDINATION OF EFFORT

A similar software development for the H-46D helicopter was conducted at the same time as this development by Caram [Ref. 1]. Because of the nature and complexity of the problem, the initial stages of these investigations were a joint effort. As a result, the Approach to the Problem (Chapter II) and the basic method of Solution (Chapter III) of this work and of Reference 1 are very similar.

B. BACKGROUND

Performance planning is an essential task to ensure the safe conduct of flight for aircrew flying any aircraft. Naval aircrew use the Naval Air Training and Operating Procedure Standardization (NATOPS) manual to acquire all necessary performance data. For the most part, NATOPS performance information is presented in a graphical format often requiring the user to transit several subcharts, which may be located on different pages, to obtain the desired performance parameter. This procedure is time consuming, prone to error, and impractical in flight.

The purpose of this thesis is to correct these NATOPS deficiencies by transforming selected performance charts into interactive, user-friendly, computer software for a hand-held programmable calculator. This solution would enable aircrew to obtain performance data with increased accuracy, reduced time and effort, and also permit use in flight.

Previously there have been several succesful efforts in NATOPS computerization. The most recent study [Ref. 2] developed software for the A-6 aircraft utilizing the Hewlett-Packard HP-41CV hand-held programmable calculator. This research demonstrated the feasibility of NATOPS performance data computerization.

C. GOALS

The first goal of this study was to generate a closed form equation for each selected NATOPS chart or subchart. The equations were required to be of a form such that independent variables were the specific chart input parameters and the dependent variable, the output parameter. The equations used to "fit" each NATOPS chart had to allow an explicit calculation of the dependent variable. Furthermore, they had to consist of standard functions (no differential/integral equations) which could be programmed on a calculator or computer.

Once the equations representing the performance charts had been derived, it was necessary to select the hardware which would be used for software design. The HP-41CV programmable calculator augmented with an extended functions module and two extended memory modules was selected. This selection was based on the small size, relatively large memory capacity (6.4 K) and the successful use in the past of the HP-41CV.

Upon completion of the software development the ultimate goal of this research was the testing of that software by a Fleet Replacement Squadron (FRS) or fleet squadron for fleet-wide implementation.

II. APPROACH TO THE PROBLEM

The overriding problem encountered was the generation of closed form equations which accurately represented each performance chart with the minimum number of terms. Minimizing the number of terms was desirable because of the calculator's limited memory space. For the majority of charts considered there were two independent input variables that yielded a single dependent output variable. This was visualized as a three dimensional surface in space.

The fitting of an equation to an arbitrary surface required the utilization of a numerical regression computer routine. These routines are numerous and have been developed into several software packages for mainframe computers. The software chosen for this study was the Biomedical Computer Program (BMDP) statistical package [Ref. 3], installed on an IBM 3033 mainframe computer located at the Naval Postgraduate School, Monterey, California.

A regression is linear in nature no matter how many independent variables are involved. However, nonlinear functions may be used in a regression if they are first "linearized". For example, if the nonlinear functions x^2, x^3, and $\ln(x)$ are transformed into independent variables U,Y, and Z, respectively, then a regression can be performed to yield an equation of the form

$$S = aU + bY + cZ + d \qquad \text{(eqn 2.1)}$$

where a, b, and c, are the regression coefficients, d is the intercept, and S is the dependent variable.

The specific BMDP program used for a majority of charts analyzed was the "all possible subsets" multiple regression program (P9R) which allows the user to input a large selection of transformed independent variables to be examined during the regression analysis. The P9R program included an option to either use all the transformed variables offered (method is none), or perform the regression selecting subsets of the offered transforms and output the subset with the best fit statistics (method is Cp).

The dominating criteria used to determine the best fit statistics was the squared multiple regression correlation (R^2). Accuracy was gauged by how close R^2 was to the ideal value of 1.0. The required R^2 for an acceptable fit was found to vary between performance charts, and was a function of what dependent output variable was being generated, the "irregularity" of the surface, and the number of independent input variables. For each chart, multiple regression analyses were performed varying the offered transforms in number and/or type, until a closed form equation was generated that yielded output that was within the accuracy of manual chart interpolation. From experience it was found that an R^2 value of .99900 (or greater) yielded a sufficiently accurate fit.

The accuracy with which a NATOPS chart could be read was subject to the design of the individual chart. In general, the following tolerances for dependent variables were established (for the regression analysis).

airspeed: ±2 KIAS
indicated torque: ±1 %
unit range: ±.001 NM/LB
fuel consumption: ±10 LB/HR
ground roll: ±10 FT

Prior to the execution of the regression program, a data file for each surface was created. The file consisted of data sets which were merely the independent variable values and the corresponding dependent variable value. For a three dimensional surface each data set consisted of three values. It was critical to ensure that the data sets extracted from a performance chart were as accurate as possible and that the data file clearly defined the surface. Obviously, those surfaces that contained "irregularities" required significantly more data sets than smoother or more "well behaved" surfaces. If a surface contained a sharp point or discontinuity, this portion of the surface was eliminated from the regression analysis due to the inability of the software to accurately fit abberations.

The tranformed variable selection was the key to successful regression analysis. Through experience one gained an intuitive feel for what type of transformed variables would yield a close fit to a surface. Fortunately, most of the surfaces responded well to regression analysis utilizing combinations of the independent variables raised to powers between one and four (polonomial regression). A standard polonomial regression program was developed containing all the possible polonomial terms up to fourth order. This standard program was used as a first attempt for fitting all charts.

For a few surfaces, obtaining a close fit by regression analysis was not possible without retaining an unacceptably large number of terms. An alternative to this was to fit each of the depicted influence curves and develop the final computer software to interpolate between curves. The trade off with an interpolation scheme was increased accuracy at the expense of increased calculator program complexity. Two examples of this method are the calculator programs "WTR T/O" and "SE RNG" found in Appendix B. Additionally, in a few cases it became necessary to use other transforms of the independent variables such as exponentials and/or high order fractional combinations of terms.

On the first execution of each regression analysis "method is none" was selected in the P9R program. This instructed the BMDP software to use all offered transforms for the regression analysis. During execution, matrix algebra was performed with the independent variables and transforms. If this algebra created numbers outside the tolerance range specified in the program (default tolerance = .0001), the "method is none" option would eliminate the offending variable, or transform, and continue execution. The resulting output contained the R^2 value along with other fit statistics and listed all terms eliminated for low tolerance. Performing a second iteration with the out-of-tolerance transforms eliminated, and with "method is Cp" selected, allowed the BMDP software to analyze subsets of the remaining transforms. Performing this two step process yielded the best fit with fewest terms for each surface.

III. THE SOLUTION

The polynomial transform program yielded acceptable regression results in the majority of cases. For the performance charts that had difficult surfaces to fit ($R^2 \geq .99900$ could not be achieved), accuracy demanded that influence lines be fit individually and interpolation be performed between them.

A. EXAMPLE SURFACE REGRESSION ANALYSIS

An engine performance chart (Figure 3.1) was chosen to illustrate the regression technique since it demonstrates the capability of numerical regression to generate an accurate closed form equation while also showing procedures for handling surface discontinuities.

The first step in the solution of this performance chart was to create the data file for the regression program. Data sets were taken along each pressure altitude influence line at increments of 20° centigrade (C) with additional points added for the sea level and 1000 foot altitude lines, due to their discontinuities. Also, a data set was included on each end of an influence line for accuracy. Each of the 75 data sets consisted of two independent variables (temperature and altitude) and the resulting dependent variable (torque). The flattened parts of the sea level and 1000 foot lines were omitted because of their discontinuities at ambient temperatures at or below -20° C.

A numerical regression was performed with the "method is none" option selected and using the standard fourth order polynomial program (22 transforms) discussed earlier. The resulting output listed the terms excluded from the regression analysis due to exceeding tolerance limits (6), the regression R^2 (.99965), and other fit statistics. The high R^2 value indicated that the selected polonomial transforms were representative of the surface.

The next step was to determine if some of the retained transforms could be eliminated without significantly effecting the fit. The six out-of-tolerance terms were deleted from the transform selection and the program was executed with the "method is Cp" option in effect. This resulted in an elimination of 10 more transforms while only degrading the R^2 value to .99952.

The equation for the surface was tested by writing a program stub with which all data points were checked to ensure accuracy. Since the surface could not be fit in its entirety, an interpolation routine was required in the final calculator program to calculate torque when the pressure altitude was between 2000 feet and sea level at ambient temperatures at or below -20° C.

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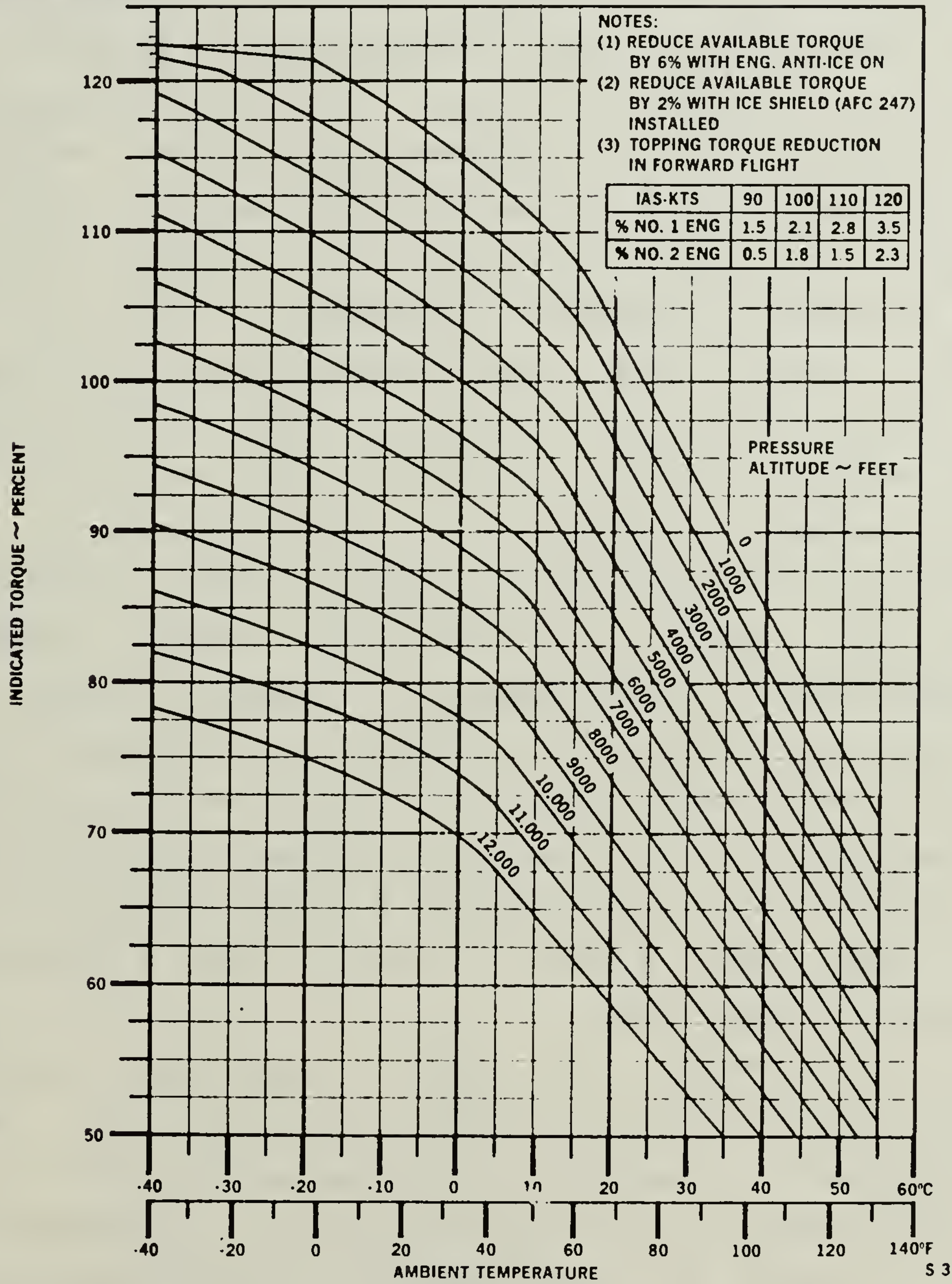
Section XI
STANDARD DATA

ENGINE PERFORMANCE

MILITARY POWER 696°C T5 OR 101% Ng
STATIC CONDITION ANTI-ICE OFF 100% Nf
ICE SHIELD (AFC 321) INSTALLED

MODEL: SH-3H
DATA AS OF 15 JANUARY 1983
DATA BASIS: CALCULATED

ENG: (2) T58-GE-10
FUEL: JP-4/JP-5
FUEL DENS. 6.5/6.8 LB/GAL



NOTES:
(1) REDUCE AVAILABLE TORQUE BY 6% WITH ENG. ANTI-ICE ON
(2) REDUCE AVAILABLE TORQUE BY 2% WITH ICE SHIELD (AFC 247) INSTALLED
(3) TOPPING TORQUE REDUCTION IN FORWARD FLIGHT

IAS-KTS	90	100	110	120
% NO. 1 ENG	1.5	2.1	2.8	3.5
% NO. 2 ENG	0.5	1.8	1.5	2.3

S 33889 (R1)

Figure 11-6. Engine Performance-Military Power (696°C T5) Chart

11-11

Figure 3.1 Engine Performance-Military Power (696°C T5)

IV. RESULTS

At the onset of this study 16 different NATOPS performance charts were selected for computerization based on their significance and frequency of use. It was anticipated that the final performance chart programs would be too voluminous to be collectively stored in the HP-41CV memory. This would have necessitated using an external mass storage device or executing individual programs piecemeal. Both of these alternatives would have had unacceptable detrimental effects. The only other alternative would have been that of contracting Hewlett-Packard to develop one or more plug-in applications modules containing the NATOPS software.

Fortunately, the majority of programs were reasonable in length and could reside in the HP-41CV's memory (augmented with extended memory) simultaneouly. A master program named "FLIGHT" was written which functioned as a software manager and assigned performance charts to specific calculator key locations (Appendix A). The master program tranferred subordinate programs from inexecutable extended memory to the executable work space in main memory, and interactively communicated with the user.

Appendix A contains the simple user instructions to execute any of the 10 listed NATOPS charts desired. With a printer attached a complete performance profile can be executed and printed for any mission plan. Appendix A also contains a listing of supplementary performance charts developed as stand-alone programs which could not reside simultaneously in the calculator's memory. Appendix B lists all surface regression equations, flow charts, and calculaor program code. It should be noted that the regression equations can be programmed for use with any capable system.

The results presented in Appendix B are for the SH-3D and SH-3H NATOPS performance charts referenced in Appendix A. Future modification of these charts would invalidate the performance software for those paticular charts.

V. CONCLUSIONS AND RECOMMENDATIONS

From the results of this thesis it can be concluded that graphical NATOPS performance data can be computerized. To effectively accomplish this, computer oriented numerical regression routines must be utilized to generate closed form equations.

Once the equations have been derived computer software can be developed that executes the programs in an expeditious, accurate, and portable fashion. Furthermore, this software can be designed for virtually any type of computer from hand-held programmable calculators to personal computers.

It is recommended that the NATOPS performance software developed in this study be submitted to a fleet squadron or Fleet Replacement Squadron (FRS) for test and evaluation. Since the software can be utilized as is, with off the shelf Hewlett-Packard components, the cost of testing would be minimized. If this software proves itself to be applicable fleet-wide, Hewlett-Packard should be contracted to develop plug-in application modules which would increase reliability and decrease execution time.

APPENDIX A

NATOPS PERFORMANCE SOFTWARE USER'S GUIDE

A. BASIC USE

The NATOPS performance software designed for the HP-41CV calculator is simple and expeditious to use. The calculator keyboard configuration is depicted in Figure A.1. As you can see, the first top two rows have abbreviated program names over the keys. The exact meaning of each performance chart abbreviation and its NATOPS [Ref. 4] figure reference are contained in Table I below.

TABLE I

NATOPS Performance Chart Reference

HP-41CV PROGRAM TITLE	NATOPS CHART TITLE	NATOPS FIGURE NUMBER
DA	Density Altitude Chart	11-3
E PERF	Engine Performance-Military Power (696°C T5) Chart	11-6
IGE	Indicated Torque to Hover in Ground Effect-10 Feet Chart	11-8
OGE	Indicated Torque to Hover out of Ground Effect Chart	11-9
STALL	Blade Stall Chart	11-5
RNG	Maximum Range-Two-Engine Chart	11-13
ENDR	Maximum Endurance-Two-Engine Chart	11-16
WTR T/O	Single Engine Water Takeoff Chart	5-9
SE RNG	Maximum Range-One-Engine Chart	11-24
SE ENDR	Maximum Endurance-One-Engine Chart	11-25

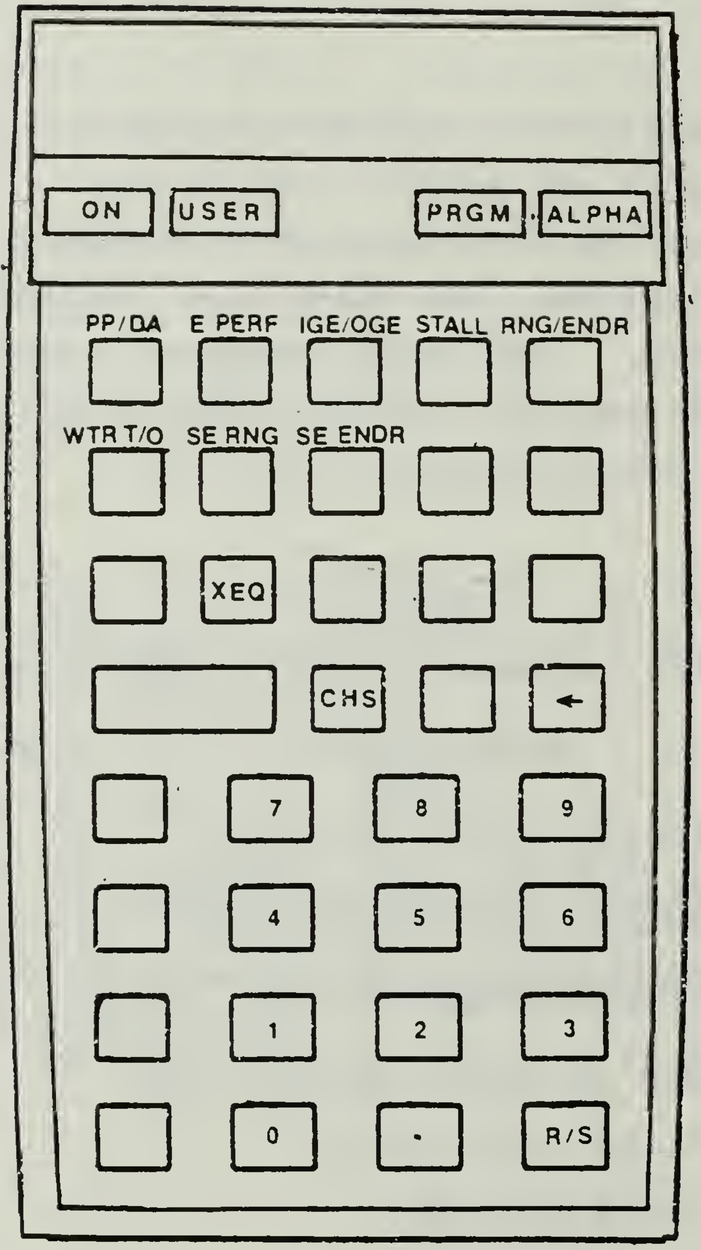


Figure A.1 Hewlett-Packard HP-41CV Calculator

The programs listed in Table I are assigned to the corresponding keys shown in Figure A.1. The key marked "PP" (Preflight Planning) executes all 10 programs successively and produces a hard copy of the output. This program requires that a printer is attached. To execute a program follow the steps presented below.

1. Turn the calculator on.
2. Press the 'XEQ' key. At this point "XEQ _ _" will be displayed. Press the 'ALPHA' key and observe "XEQ _" and the word "ALPHA" in the display. Type in the word "FLIGHT" and again press the 'ALPHA' key. You will see "PRGM" flash in the display followed by a constant "READY".
3. Find the key with the paticular performance chart desired and push it. As the program is initiated the calculator will prompt the user for any needed information. The exact prompt meanings are defined below:
   - PA? (FT) - pressure altitude in FT.
   - DA? (FT) - density altitude in FT.
   - OAT? (C) - outside air temperature in °C.
   - GWT? (LB) - gross weight in LB.
   - WIND? (KT) - head wind in KT.
   - NR? (%) - rotor RPM in per cent.
   - <BANK? (DEG) - angle of bank in degrees.
   - FUEL? (LB) - fuel on board in LB.
4. Answer the prompt by pushing the corresponding numbered keys until the desired value is seen in the display. If a mistake is made, simply push the key with the horizontal arrow (far right column, four keys from the top) and re-enter the number. If the number to be entered is negative (negative OAT), push the key marked CHS after the number has been entered in the display. When the desired number is displayed in the window push the key marked R/S (run/stop, bottom right key).

5. After all the prompts required have been answered the calculator will execute the program. While the calcualtor is working "PRGM" will be visible in the display. As the calculator generates answers they are shown in the display. Some charts yield more than one performance parameter, so it is necessary to note each parameter displayed and then push the R/S key to continue execution.
6. Once all performance parameters have been calculated, pushing R/S will display "READY" which tells the user he has been given all available output and the calculator is ready to execute the next program.
7. Before executing the "PP" program ensure the calculator is turned off. With the printer also turned off, plug the printer input chord into the only remaining extension port. Turn the calculator and printer on, select the normal mode on the printer, and push the "PP" key. All other instructions remain the same.

B. SUPPLEMENTARY PROGRAMS

In addition to the performance charts listed in Table I, six additional charts have been computerized and listed in Table II. Due to their large sizes and/or aplicability only to Functional Checkflights, they were developed strictly as stand-alone programs. They must be loaded and executed as discussed in Section D of this Appendix. After execution begins, these programs will appear to the user to operate exactly like the programs listed in Table I.

C. GENERAL USER INFORMATION

The NATOPS software should generate accurate answers within the range of a selected performance chart. If data

TABLE II

Supplementary NATOPS Performance Chart Reference

HP-41CV PROGRAM TITLE	NATOPS CHART TITLE	NATOPS FIGURE NUMBER
MIN Q	Engine Performance-Topping Power (721°C T5) Chart	3-12
RPM	Low Pitch Autorotative RPM Chart	3-14
TEMP	Temperature Conversion Chart	11-2
NP Q	Engine Performance-Normal Power (660°C T5) Chart	11-7
ENVLP	Ability to Maintain Level Flight One-Engine Chart	11-22
ROLL	Landing Distance Ground Roll-Power Off Chart	11-26

is entered erroneously, or in excess of a paticular chart's range, the output will be in error.

In the cases where a chart has limitations such as Ability to Maintain Level Flight - One-Engine Chart [Ref. 4: p. 11-37], these have been taken into account within the program and the output will tell the user if they exceed that limitation. If the user is ever in doubt as to the validity of the calculator generated performance data, the NATOPS manual should be consulted.

D. INITIAL CALCULATOR PREPARATION

The basic use instructions assume the user has a calcualator that has all the performance software installed. If the user merely has the calculator (with two extended memory modules and an extended functions module), a card reader, and the NATOPS software program cards; several steps must be taken before the calculator can be used as described earlier.

1. Become familiar with the HP-41CV owner's manual and the operating instructions of all peripherals. While the occasional user can avoid an in depth knowledge of the system, initial set up requires someone who is familiar with the hardware and procedures listed in References 5,6, and 7.
2. With the extended memory and extended functions modules in their proper ports, and with the card reader attached, loading the programs into main and extended memory can begin.
    - Load the following programs into extended memory: "DA, E PERF, IGE, OGE, STALL, RNG, ENDR, WTR T/O, SE RNG, and SE ENDR".
    - Load "FLIGHT" into main memory. You may also load "TEMP" if required.
3. Ensure the only programs in main memory are the ones listed above and erase any other programs.
4. Pack the programs in main memory.
5. Execute the program "FLIGHT".

When "READY" appears in the display the calculator is ready for program execution.

E. CALCULATOR FLAGS

Flags 1 through 3 are used for condition checking in the execution of some programs. If the programs are always allowed to run to completion (the user presses R/S until "READY" appears in the display) these flags will be cleared. If the user stops execution before completion and executes another program, there is a possibility that the second program will produce an output that is in error.

F. CALCULATOR MEMORY REGISTERS

Memory registers and their contents are shown below:

Registers	Contents
00-07	Scratch
08	PA
09	GWT
10	DA
11	Wind
12-14	Scratch
15	$(OAT)^2$
16	$(OAT)^3$
17	$(OAT)^4$
18	$(PA)^2$
19	$(PA)^3$
20	$(PA)^4$
21	$(PA)^6$
22	$(GWT)^2$
23	$(GWT)^3$
24	$(GWT)^4$
25	$(GWT)^5$
26	$(GWT)^6$
27	$(DA)^3$
28	$(Wind)^2$
29	$(Wind)^4$
30	OAT
31	HIGE Q
32	HOGE Q
33	Blade Stall KIAS
34	Max Range KIAS
35	Max Range Unit Range
36	Max Endurance KIAS
37	Max Endurance Fuel Consumption
38	Engine Performance (Military) Q
39	Water Takeoff KIAS
40	S/E Max Range KIAS
41	S/E Max Range Unit Range
42	S/E Max Endurance KIAS
43	S/E Max Endurance Fuel Consumption

Note: An explanation of abbreviations may be found in Appendix B.

APPENDIX B

REGRESSION EQUATIONS AND SOFTWARE DOCUMENTATION

This appendix contains all regression equations and curve fits generated for each NATOPS chart considered. It also contains the associated calculator program code, flow charts, and the tested accuracy of the output. Although regression equations are of the form shown in equation 2.1, they are presented in tabular form due to their large sizes. The flow charts use standard symbology and depict the general programming logic but little detail. The computer code listings are in the Reverse Polish Notation (RPN) language developed by Hewlett-Packard.

TABLE III

Variable Abbreviations

ABBREVIATION	VARIABLE	UNIT
BLi	"ith" Base Line (number omitted if only one)	--
(K) CAS	Calibrated Air Speed	KT
DA	Density Altitude	FT
EAS	Equivalent Air Speed	KT
GWT	Gross Weight	LB
(K) IAS	Indicated Air Speed	KT
Nr	Rotor Speed	RPM
OAT	Outside Air Temperature	°C
PA	Pressure Altitude	FT
Q	Indicated Torque	%
TAS	True Air Speed	KT
UR	Unit Range	NM/LB

A. ENGINE PERFORMANCE - TOPPING (721°C T5)

Program Title: MIN Q

Accuracy: ±1% Q

Independent Variables:

$A = PA/1000$

$B = OAT$

Relationships:

For PA = sea level $OAT \leq 10$

$Q = -.070\ B + 119.7$

For PA = sea level $OAT \geq 10$

$Q = -.811\ B + 127.1$

For PA = 1000 $OAT \leq -10$

$Q = -.067\ B + 119.3$

For PA = 1000 $-10 \leq OAT \leq 10$

$Q = -.250\ B + 117.5$

For PA = 1000 $OAT \geq 10$

$Q = -.778\ B + 122.8$

For PA = 2000 $OAT \leq -22$

$Q = -.056\ B + 118.8$

For PA = 2000 $-22 \leq OAT \leq 10$

$Q = 113.5 \exp[-.00248\ B]$

For PA = 2000 $OAT \geq 10$

$Q = -.756\ B + 118.3$

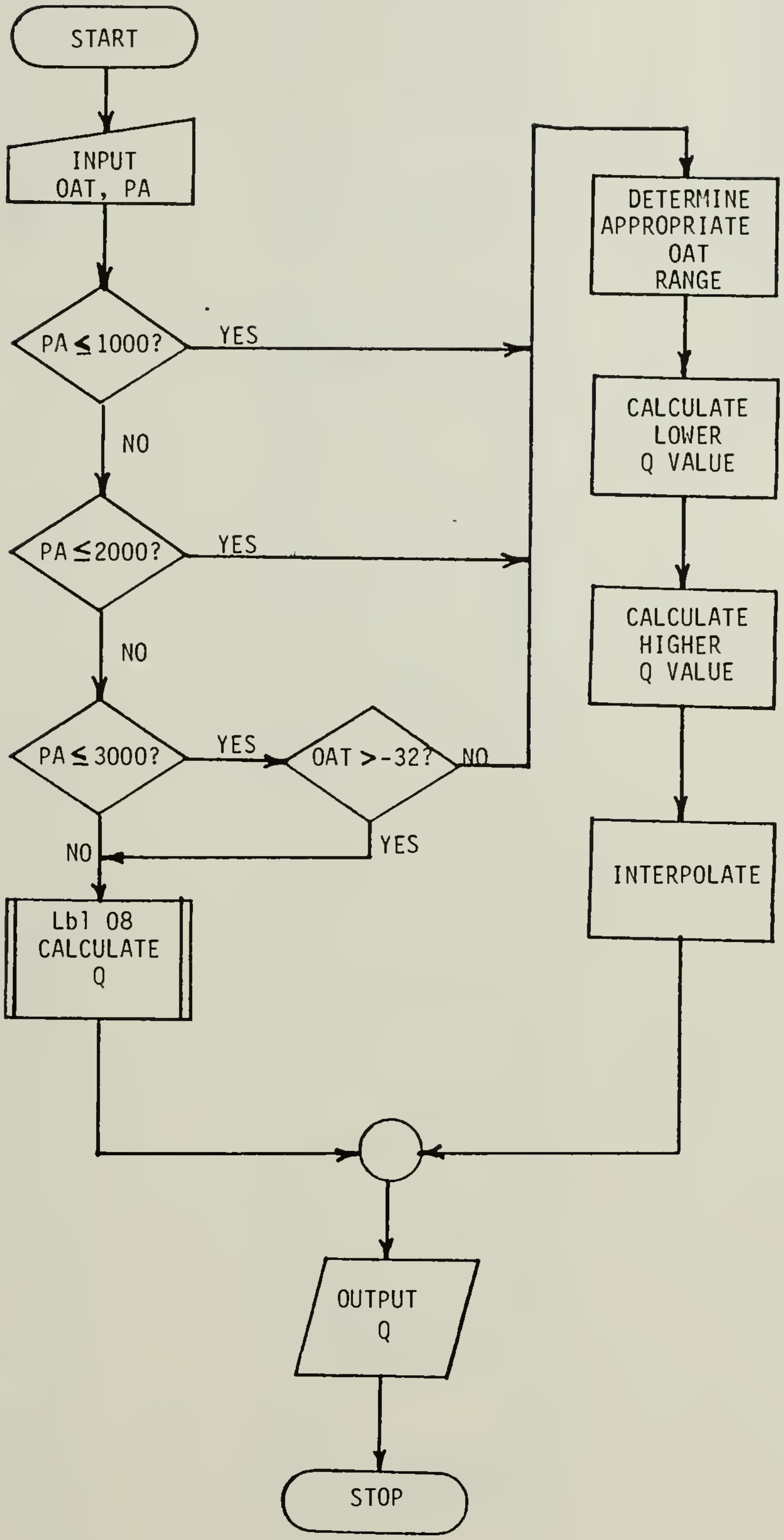
For PA = 3000 $OAT \leq -32$

$Q = -.100\ B + 116.3$

Remainder of chart is regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	122.151
A	-4.30544
B	$-.378299$
A^3B^3	$.316746 \times 10^{-7}$
A^2	5.33051×10^{-2}
A^2B	-5.69557×10^{-4}
A^2B^4	$-.726407 \times 10^{-8}$
AB	1.27824×10^{-2}
AB^2	2.19656×10^{-4}
B^2	-7.45649×10^{-3}
B^3	-9.76376×10^{-5}
B^4	$.228517 \times 10^{-5}$

MIN Q


START
INPUT OAT, PA
PA ≤ 1000?
YES
NO
PA ≤ 2000?
YES
NO
PA ≤ 3000?
YES
NO
OAT > -32?
NO
YES
Lbl 08 CALCULATE Q
DETERMINE APPROPRIATE OAT RANGE
CALCULATE LOWER Q VALUE
CALCULATE HIGHER Q VALUE
INTERPOLATE
OUTPUT Q
STOP

```
01♦LBL "MIN Q"
02 FIX 0
03 CF 27
04 "OAT ?  "
05 40
06 XTOA
07 "├C"
08 41
09 XTOA
10 PROMPT
11 STO 01
12 "PA ?  "
13 40
14 XTOA
15 "├FT"
16 41
17 XTOA
18 PROMPT
19 1000
20 /
21 STO 02
22 1
23 X<>Y
24 X>Y?
25 GTO 06
26 XEQ A
27 STO 07
28 GTO D
29♦LBL 06
30 2
31 RCL 02
32 X>Y?
33 GTO 07
34 XEQ B
35 STO 07
36 GTO D
37♦LBL 07
38 3
39 RCL 02
40 X>Y?
41 GTO 08
42 -32
43 RCL 01
44 X>Y?
45 GTO 08
46 XEQ C
47 STO 07
48 GTO D
49♦LBL 08
50 RCL 02
51 X↑2
52 STO 03
53 RCL 01
54 X↑2
55 STO 04
56 RCL 01
57 3
58 Y↑X
59 STO 05
60 RCL 01
61 *
62 STO 06
63 .228517 E-5
64 *
65 122.151
66 +
67 RCL 02
68 -4.30544
69 *
70 +
71 RCL 01
72 -.378299
73 *
74 +
75 RCL 02
76 3
77 Y↑X
78 RCL 05
79 *
80 .316746 E-7
81 *
82 +
83 RCL 03
84 .0533051
85 *
86 +
87 RCL 03
88 RCL 01
89 *
90 -.000569557
91 *
92 +
93 RCL 03
94 RCL 06
95 *
96 -.726407 E-8
97 *
98 +
99 RCL 01
100 RCL 02
101 *
102 .0127824
103 *
104 +
105 RCL 02
106 RCL 04
107 *
108 .000219656
109 *
110 +
111 RCL 04
112 -.00745649
113 *
114 +
115 RCL 05
116 -.0000976376
117 *
118 +
119 STO 07
120♦LBL D
121 TONE 0
122 "MIN Q= "
123 ARCL 07
124 "├ %"
125 PROMPT
126 GTO "MIN Q"
127♦LBL A
128 1
129 RCL 02
130 X=Y?
131 GTO H
132 X=0?
133 GTO I
134 XEQ H
135 XEQ I
136 RCL 05
137 -
138 RCL 02
139 *
140 RCL 05
141 +
142 STO 07
143 RTN
144♦LBL B
145 2
146 RCL 02
147 X=Y?
148 GTO G
149 XEQ G
150 XEQ H
```

```
151 RCL 04
152 -
153 RCL 02
154 1
155 -
156 *
157 RCL 04
158 +
159 STO 07
160 RTN
161+LBL C
162 3
163 RCL 02
164 X=Y?
165 GTO F
166 XEQ F
167 XEQ G
168 RCL 03
169 -
170 RCL 02
171 2
172 -
173 *
174 RCL 03
175 +
176 STO 07
177 RTN
178+LBL F
179 RCL 01
180 -.1
181 *
182 116.3
183 +
184 STO 03
185 RTN
186+LBL G
187 -22
188 RCL 01
189 X>Y?
190 GTO 01
191 -.056
192 *
193 118.8
194 +
195 STO 04
196 RTN
197+LBL 01
198 10
199 RCL 01
200 X>Y?
201 GTO 02
202 -.002478135
203 *
204 E↑X
205 113.49153
206 *
207 STO 04
208 RTN
209+LBL 02
210 RCL 01
211 -.756
212 *
213 118.3
214 +
215 STO 04
216 RTN
217+LBL H
218 -10
219 RCL 01
220 X>Y?
221 GTO 03
222 -.067
223 *
224 119.3
225 +
226 STO 05
227 RTN
228+LBL 03
229 10
230 RCL 01
231 X>Y?
232 GTO 04
233 -.25
234 *
235 117.5
236 +
237 STO 05
238 RTN
239+LBL 04
240 RCL 01
241 -.778
242 *
243 122.6
244 +
245 STO 05
246 RTN
247+LBL I
248 10
249 RCL 01
250 X>Y?
251 GTO 05
252 -.07
253 *
254 119.7
255 +
256 STO 06
257 RTN
258+LBL 05
259 RCL 01
260 -.811
261 *
262 127.1
263 +
264 STO 06
265 .END.
```

B. LOW PITCH AUTO RPM

Program Title: RPM

Accuracy: Exact

Independent Variables:

A = PA
B = CAT
C = GWT
D = Nr (for GWT = 17,000)

Relationship:

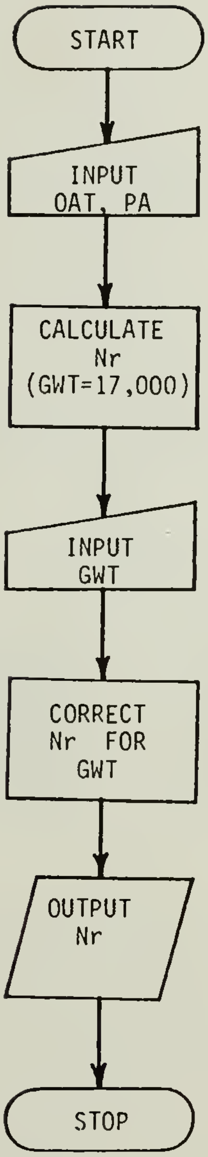
For the table value (GWT = 17,000)

$$D = [A + 1000]/500 + 100 + [B + 10]/5$$

The table value is corrected for the actual GWT by

$$Nr = 3.5[C/1000 - 17] + D$$

RPM


START
INPUT
OAT, PA
CALCULATE
Nr
(GWT=17,000)
INPUT
GWT
CORRECT
Nr FOR
GWT
OUTPUT
Nr
STOP

```
01♦LBL "RPM"
02 FIX 1
03 "OAT ?  "
04 40
05 XTOA
06 "⊢C"
07 41
08 XTOA
09 PROMPT
10 STO 01
11 "PA ?  "
12 40
13 XTOA
14 "⊢FT"
15 41
16 XTOA
17 PROMPT
18 1 E3
19 +
20 500
21 /
22 100
23 +
24 RCL 01
25 10
26 +
27 5
28 /
29 +
30 "GWT ?  "
31 40
32 XTOA
33 "⊢LB"
34 41
35 XTOA
36 PROMPT
37 RCL T
38 X<>Y
39 1000
40 /
41 17
42 -
43 3.5
44 *
45 +
46 "MIN HR= "
47 ARCL X
48 PROMPT
49 GTO "RPM"
50 END
```

C. SINGLE ENGINE WATER TAKEOFF

Program Title: WTR T/O

Accuracy: ±1 KIAS

Independent Variables:

$A = OAT/10$

$B = GWT$

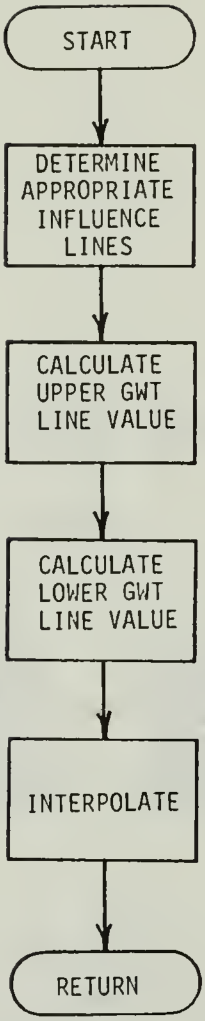
Relationships: All influence lines are of the form

$$KIAS = 10\,[a \exp(b\,A) + c \exp(d\,A)]$$

GWT	a	b	c	d
15,000	1.367275	-.588256	.385220	.554372
16,000	1.741077	.098931	.015010	1.250304
17,000	2.329929	.082539	.012430	1.319411
18,000	2.715378	.082631	.027075	1.205079
19,000	3.227943	.074984	.010291	1.675218
20,000	3.792946	.070861	.003270	2.524752

Note: This program is not valid for GWT > 20,000. Also, if the computed KIAS is greater than 70 KT, the display will show 999 KT indicating an inaccurate output. If the computed KIAS is less than 15 KT, the display will show 15 KT indicating that a takeoff is possible regardless of the wind conditions.

WTR T/O


START
DETERMINE APPROPRIATE INFLUENCE LINES
CALCULATE UPPER GWT LINE VALUE
CALCULATE LOWER GWT LINE VALUE
INTERPOLATE
RETURN

WTR T/O KIAS STORED R_{39}

```
01♦LBL "WTR T/O"
02 016.020
03 STO 06
04♦LBL 04
05 RCL 06
06 INT
07 RCL 09
08 X<=Y?
09 GTO 05
10 ISG 06
11 GTO 04
12 GTO 06
13♦LBL 05
14 -
15 STO 07
16 XEQ IND 06
17 XEQ 13
18 XEQ 14
19 STO 05
20 1
21 ST- 06
22 XEQ IND 06
23 XEQ 13
24 XEQ 14
25 RCL 05
26 -
27 RCL 07
28 *
29 RCL 05
30 +
31 10
32 *
33 70
34 X<=Y?
35 GTO 06
36 RDN
37 15
38 X<=Y?
39 RDN
40 STO 39
41 RTN
42♦LBL 06
43 999
44 STO 39
45 RTN
46♦LBL 13
47 STO 03
48 RDN
49 STO 02
50 RDN
51 STO 01
52 RDN
53 STO 00
54 RTN
55♦LBL 14
56 RCL 01
57 RCL 30
58 10
59 /
60 STO 12
61 *
62 E↑X
63 RCL 00
64 *
65 RCL 03
66 RCL 12
67 *
68 E↑X
69 RCL 02
70 *
71 +
72 RTN
73♦LBL 15
74 1.3673
75 -.5883
76 .3852
77 .5544
78 RTN
79♦LBL 16
80 1.7411
81 .09093
82 .01501
83 1.2503
84 RTN
85♦LBL 17
86 2.33
87 .082539
88 .01243
89 1.31941
90 RTN
91♦LBL 18
92 2.7154
93 .08263
94 .027075
95 1.2051
96 RTN
97♦LBL 19
98 3.228
99 .074984
100 .01029
101 1.67522
102 RTN
103♦LBL 20
104 3.793
105 .07006
106 .00327
107 2.52475
108 .END.
```

D. AIRSPEED CALIBRATION

Program Title: (not developed as a separate program)

Accuracy: ±.25 KIAS

Relationship:

$$IAS = 1.03581(CAS) - 5.530087$$

Note: The climb curve and the descent curve were not fit. Although the level flight curve was not developed as a separate program, the relationship was used in several other programs to convert CAS to IAS.

E. TEMPERATURE CONVERSION

Program Title: TEMP

Accuracy: Exact

Independent Variables:

F = °F

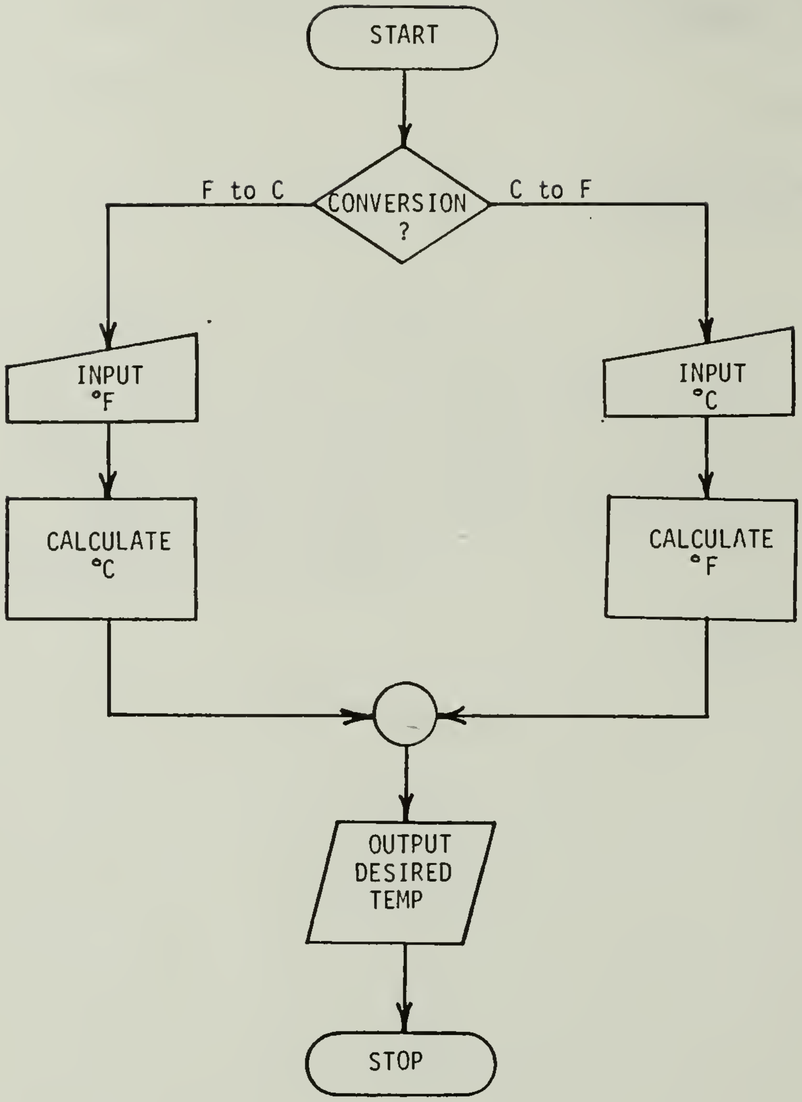
C = °C

Relationships:

$$F = (9/5)C + 32$$

$$C = 5(F - 32)/9$$

TEMP


START
CONVERSION ?
F to C
C to F
INPUT °F
INPUT °C
CALCULATE °C
CALCULATE °F
OUTPUT DESIRED TEMP
STOP

```
01♦LBL "TEMP"
02 FIX 1
03 SF 27
04 "NEED?   C  F"
05 PROMPT
06♦LBL D
07 CF 27
08 "DEG F ?"
09 PROMPT
10 32
11 -
12 5
13 *
14 9
15 /
16 "DEG C= "
17 GTO 01
18♦LBL E
19 CF 27
20 "DEG C ?"
21 PROMPT
22 9
23 *
24 5
25 /
26 32
27 +
28 "DEG F= "
29♦LBL 01
30 ARCL X
31 PROMPT
32 GTO "TEMP"
33 END
```

F. DENSITY ALTITUDE

Program Title: DA

Accuracy: Exact

Variables:

T = ratio of OAT to SSL temperature
P = ratio of atmospheric pressure to SSL pressure
D = ratio of air density to SSL density
H = actual tapeline altitude(FT)
Hr = DA
Hp = PA
k = temperature lapse rate for standard atmosphere

Relationships:

$P = D\ T = T^{5.260559}$ [Ref. 8]

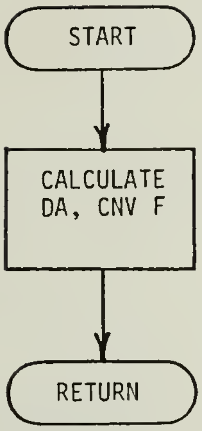
$T = [273.15 + OAT]/288.15 = 1 - k\ H$

$P = [1 - k\ Hp]^{5.260559}$

$D = [1 - k\ Hr]^{4.260559}$

$TAS = D^{-.5}\ EAS$ [Ref. 9]

DA



DA STORED R_{10}

```
01♦LBL "DA"
02 RCL 08
03 6.863 E-3
04 *
05 CHS
06 1
07 +
08 5.260559
09 Y↑X
10 RCL 30
11 273.15
12 +
13 288.15
14 /
15 /
16 STO 00
17 .234711
18 Y↑X
19 CHS
20 1
21 +
22 6.863 E-3
23 /
24 STO 10
25 .END.
```

G. BLADE STALL

Program Title: STALL

Accuracy: ±2 KIAS

Upper Chart

Independent Variables:

A = PA/1000

B = OAT

Relationship: Regression equation with BL1 as the dependent variable.

Term	Coefficient
Intercept	5.56893
A	-.223872
B	-5.56144 X 10^{-2}
A^3	1.09302 X 10^{-3}
A^2	-1.99009 X 10^{-2}
A^2B	-5.58699 X 10^{-4}
A^2B^2	1.72716 X 10^{-5}
A^2B^3	.581095 X 10^{-6}
A^2B^4	-.135402 X 10^{-7}
AB	7.82900 X 10^{-3}
AB^2	-2.47111 X 10^{-4}
AB^3	-.744059 X 10^{-5}
AB^4	.182777 X 10^{-6}
B^2	8.76430 X 10^{-4}
B^3	1.96684 X 10^{-5}
B^4	-.525713 X 10^{-6}

Second Chart

Independent Variables:

A = BL1

B = Nr

Relationship: Regression equation with BL2 as the dependent variable.

Term	Coefficient
Intercept	-20.000000
A	1.000000
B	.200000
AB^4	.164047 X 10^{-22}
B^3	-.472667 X 10^{-17}

Third Chart

Independent Variables:

A = GWT/1000

B = BL2

Relationships: Regession equation with BL3 as the dependent variable.

Term	Coefficient
Intercept	10.396600
A	-.599163
B	1.00460
A^2	7.47972×10^{-2}

Bottom Chart

Independent Variables:

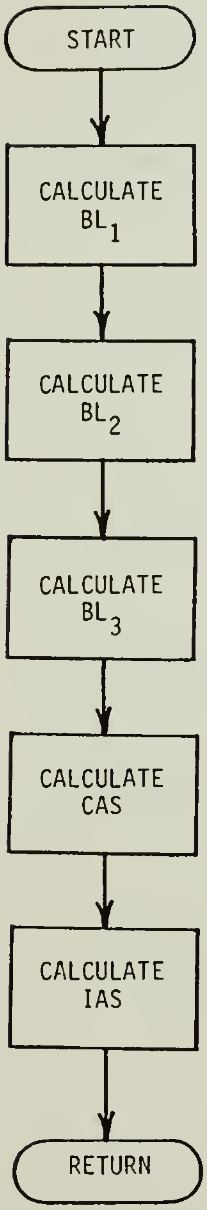
A = angle of bank

B = BL3

Relationship: Regession equation with CAS as the dependent variable.

Term	Coefficient
Intercept	-7.79009×10^{-2}
A	-.120130
B	20.0189
A^4	$-.327492 \times 10^{-5}$
A^2	-1.22325×10^{-2}
AB	-7.49109×10^{-2}
AB^2	1.39609×10^{-2}
AB^3	-7.73984×10^{-4}

STALL



BLADE STALL KIAS STORED R_{33}

```
01*LBL "STALL"
02 RCL 08
03 -.223872
04 *
05 5.56893
06 +
07 RCL 30
08 -5.56144 E-2
09 *
10 +
11 RCL 19
12 1.093 E-3
13 *
14 +
15 RCL 18
16 -1.99 E-2
17 *
18 +
19 RCL 18
20 RCL 30
21 *
22 -5.587 E-4
23 *
24 +
25 RCL 18
26 RCL 15
27 *
28 1.72716 E-5
29 *
30 +
31 RCL 18
32 RCL 16
33 *
34 .5811 E-6
35 *
36 +
37 RCL 18
38 RCL 17
39 *
40 -.1354 E-7
41 *
42 +
43 RCL 08
44 RCL 30
45 *
46 7.829 E-3
47 *
48 +
49 RCL 08
50 RCL 15
51 *
52 -2.47111 E-4
53 *
54 +
55 RCL 08
56 RCL 16
57 *
58 -.7440759 E-5
59 *
60 +
61 RCL 08
62 RCL 17
63 *
64 .182777 E-6
65 *
66 +
67 RCL 15
68 8.7643 E-4
69 *
70 +
71 RCL 16
72 1.96684 E-5
73 *
74 +
75 RCL 17
76 -.525713 E-6
77 *
78 +
79 ENTER↑
80 -20
81 +
82 X<>Y
83 RCL 00
84 4
85 Y↑X
86 *
87 .164047 E-22
88 *
89 +
90 RCL 00
91 3
92 Y↑X
93 -.472667 E-17
94 *
95 +
96 RCL 00
97 .2
98 *
99 +
100 1.0046
101 *
102 10.4
103 +
104 RCL 09
105 -.599163
106 *
107 +
108 RCL 22
109 7.47972 E-3
110 *
111 +
112 STO 02
113 20.8169
114 *
115 -7.79 E-2
116 +
117 RCL 01
118 -.12013
119 *
120 +
121 RCL 01
122 4
123 Y↑X
124 -.327492 E-5
125 *
126 +
127 RCL 01
128 X↑2
129 -1.22325 E-2
130 *
131 +
132 RCL 01
133 RCL 02
134 *
135 -7.49109 E-2
136 *
137 +
138 RCL 02
139 X↑2
140 RCL 01
141 *
142 1.39609 E-2
143 *
144 +
145 RCL 02
146 3
147 Y↑X
148 RCL 01
149 *
150 -7.73984 E-4
```

```
151 *
152 +
153 1.03561
154 *
155 5.53
156 -
157 STO 33
158 .END.
```

H. ENGINE PERFORMANCE - MILITARY (696°C T5)

Program Title: E PERF

Accuracy: ±1% Q

Independent Variables:

$A = PA/1000$

$B = OAT$

Relationships:

For $PA =$ sea level $OAT \leq -20$

$Q = -.05\ B + 120.5$

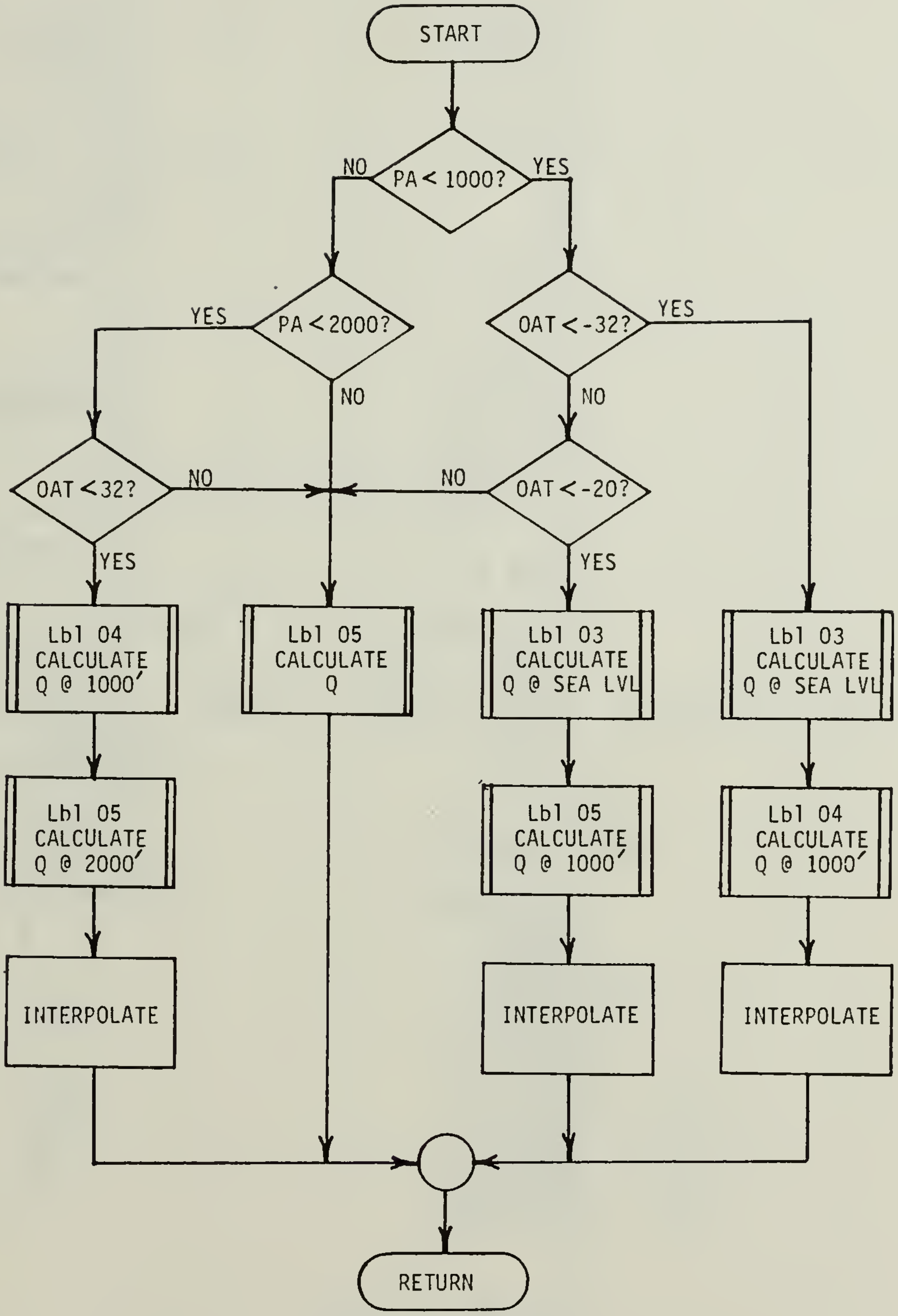
For $PA = 1000$ $OAT \leq -32$

$Q = -.0938\ B + 118$

Remainder of chart is regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	115.448
A	-3.76123
B	-.408791
A^2B	9.78404×10^{-4}
AB	-9.34240×10^{-3}
AB^3	$.749596 \times 10^{-5}$
B^2	-8.34115×10^{-3}
B^3	-7.24488×10^{-5}
B^4	$.164096 \times 10^{-5}$

E PERF



ENGINE PERFORMANCE Q
STORED R_{38}

```
01♦LBL "E PERF"
02 1
03 RCL 08
04 X>Y?
05 GTO 02
06 -32
07 RCL 30
08 X>Y?
09 GTO 01
10 XEQ 03
11 ENTER↑
12 XEQ 04
13 -
14 RCL 08
15 *
16 -
17 STO 38
18 RTN
19♦LBL 01
20 -20
21 X<>Y
22 X>Y?
23 GTO 05
24 RCL 06
25 STO 01
26 1
27 STO 08
28 STO 12
29 XEQ 03
30 XEQ 05
31 -
32 RCL 01
33 *
34 RCL 00
35 -
36 CHS
37 STO 38
38 GTO 07
39♦LBL 02
40 2
41 RCL 08
42 X>Y?
43 GTO 05
44 -32
45 RCL 30
46 X>Y?
47 GTO 05
48 RCL 08
49 STO 01
50 2
51 STO 08
52 X↑2
53 STO 18
54 XEQ 04
55 XEQ 05
56 -
57 RCL 01
58 1
59 -
60 *
61 RCL 00
62 -
63 CHS
64 STO 38
65 GTO 07
66♦LBL 03
67 RCL 30
68 -.05
69 *
70 120.5
71 +
72 STO 00
73 RTN
74♦LBL 04
75 RCL 30
76 -.0936
77 *
78 118
79 +
80 STO 00
81 RTN
82♦LBL 05
83 RCL 08
84 -3.76123
85 *
86 115.448
87 +
88 RCL 30
89 -.406791
90 *
91 +
92 RCL 12
93 RCL 30
94 *
95 9.78404 E-4
96 *
97 +
98 RCL 08
99 RCL 30
100 *
101 -9.3424 E-7
102 *
103 +
104 RCL 08
105 RCL 16
106 *
107 7.49596 E-6
108 *
109 +
110 RCL 15
111 -8.34115 E-3
112 *
113 +
114 RCL 16
115 -7.24488 E-5
116 *
117 +
118 RCL 17
119 1.64096 E-6
120 *
121 +
122 STO 38
123 RTN
124♦LBL 07
125 RCL 01
126 STO 08
127 X↑2
128 STO 18
129 .END.
```

I. ENGINE PERFORMANCE - NORMAL (660°C T5)

Program Title: NP Q

Accuracy: ±1% Q

Independent Variables:

$A = PA/1000$

$B = OAT$

Relationships:

For PA = sea level $OAT \leq -18$

$$Q = -.0568\ B + 119.4800$$

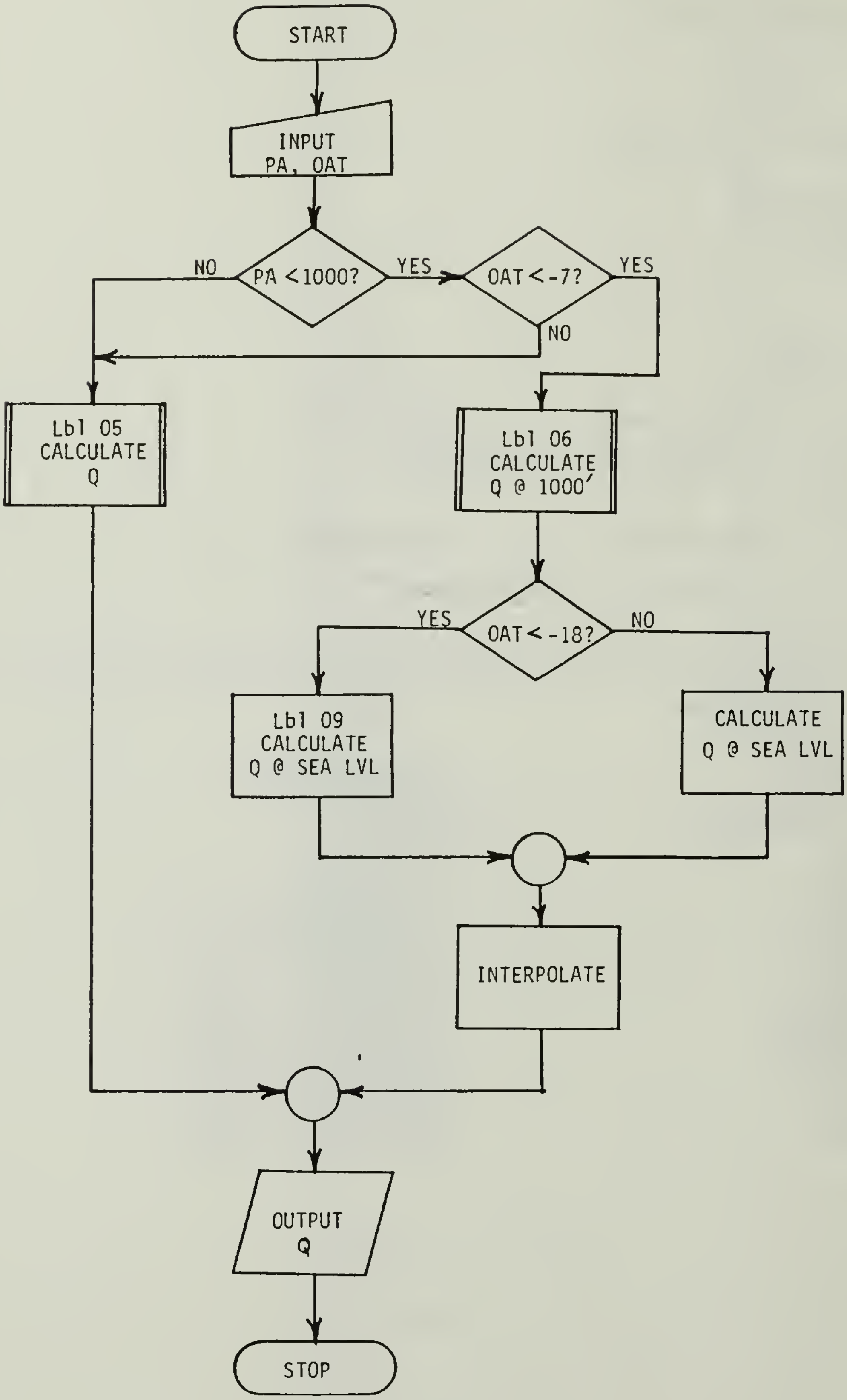
For PA = sea level $-18 \leq OAT \leq -7$

$$Q = -.2727\ B + 115.5914$$

Remainder of chart is regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	111.627
A	-5.76421
B	-.797907
A^4B^2	$.847954 \times 10^{-6}$
A^3	-.0144287
A^3B^3	$-.252248 \times 10^{-6}$
A^2	.336850
A^2B	1.61809×10^{-3}
A^2B^2	-3.23450×10^{-4}
A^2B^3	$.453896 \times 10^{-5}$
AB^2	2.96853×10^{-3}
AB^3	-2.90769×10^{-5}
B^2	-1.18752×10^{-2}
B^3	1.73129×10^{-4}

NP Q


START
INPUT PA, OAT
PA < 1000?
NO
YES
OAT < -7?
YES
NO
Lbl 05 CALCULATE Q
Lbl 06 CALCULATE Q @ 1000′
OAT < -18?
YES
NO
Lbl 09 CALCULATE Q @ SEA LVL
CALCULATE Q @ SEA LVL
INTERPOLATE
OUTPUT Q
STOP

```
01♦LBL "NP Q"
02 "PA ?  "
03 40
04 XTOA
05 "├FT"
06 41
07 XTOA
08 PROMPT
09 1 E3
10 /
11 STO 01
12 "OAT ?  "
13 40
14 XTOA
15 "├C"
16 41
17 XTOA
18 PROMPT
19 STO 05
20 XEQ 01
21 FIX 0
22 TONE 0
23 "Q= "
24 ARCL X
25 "├ %"
26 PROMPT
27 FIX 4
28 STOP
29 GTO "NP Q"
30♦LBL 01
31 RCL 05
32 6.008
33 XEQ 07
34 RCL 01
35 1
36 X<=Y?
37 GTO 05
38 -7
39 RCL 05
40 X>Y?
41 GTO 05
42 RCL 01
43 STO 00
44 1
45 STO 01
46 2.004
47 XEQ 07
48 XEQ 06
49 STO 10
50 RCL 05
51 -18
52 X>Y?
53 GTO 09
54 RCL 05
55 -.2727
56 *
57 115.6
58 +
59♦LBL 10
60 RCL X
61 RCL 10
62 -
63 RCL 00
64 *
65 -
66 RTN
67♦LBL 05
68 RCL 01
69 2.004
70 XEQ 07
71♦LBL 06
72 RCL 01
73 -5.76421
74 *
75 111.627
76 +
77 RCL 05
78 -.797907
79 *
80 +
81 RCL 04
82 RCL 06
83 *
84 .847954 E-6
85 *
86 +
87 RCL 03
88 -.0144287
89 *
90 +
91 RCL 03
92 RCL 07
93 *
94 -.252248 E-6
95 *
96 +
97 RCL 02
98 .33685
99 *
100 +
101 RCL 02
102 RCL 05
103 *
104 1.61809 E-3
105 *
106 +
107 RCL 02
108 RCL 06
109 *
110 -3.2345 E-4
111 *
112 +
113 RCL 02
114 RCL 07
115 *
116 .453896 E-5
117 *
118 +
119 RCL 01
120 RCL 06
121 *
122 2.96853 E-3
123 *
124 +
125 RCL 01
126 RCL 07
127 *
128 -2.90769 E-5
129 *
130 +
131 RCL 06
132 -.0118752
133 *
134 +
135 RCL 07
136 1.73129 E-4
137 *
138 +
139 RTN
140♦LBL 07
141 STO 09
142 X<>Y
143 RCL X
144 RCL X
145 X↑2
146♦LBL 08
147 STO IND 09
148 *
149 ISG 09
150 GTO 08
```

```
151 RTN
152♦LBL 09
153 RCL 05
154 -.0568
155 *
156 119.5
157 +
158 GTO 10
159 .END.
```

J. TORQUE TO HOVER IN GROUND EFFECT

Program Title: IGE

Accuracy: ±1% Q

Upper Chart

Independent Variables:

A = DA/1000

B = GWT/1000

Relationship: Regression equation with BL as the dependent variable.

Term	Coefficient
Intercept	-10.3038
A	.212035
B	.751590
A^4B^3	.160505 X 10^{-7}
A^3	-6.61526 X 10^{-4}
A^2B^4	.165210 X 10^{-6}
AB^3	-1.90443 X 10^{-4}
AB^4	.993143 X 10^{-5}
B^4	1.21211 X 10^{-5}

Lower Chart

Independent Variables:

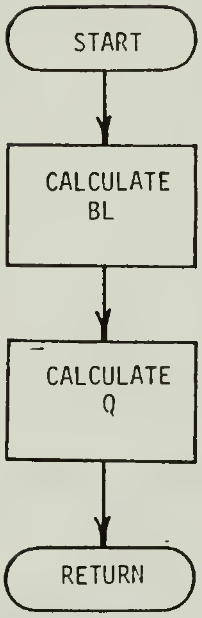
A = Wind

B = BL

Relationship: Regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	50.2504
B	4.97996
A^4	5.72239 X 10^{-5}
A^4B^3	.548313 X 10^{-7}
A^4B^4	-.193279 X 10^{-8}
A^3	-2.29042 X 10^{-3}
A^3B^2	-2.03324 X 10^{-5}
A^2B^2	1.96829 X 10^{-4}

IGE



HIGE Q STORED R_{31}

```
01♦LBL "IGE"
02 RCL 10
03 .212035
04 *
05 -10.3038
06 +
07 RCL 09
08 .75159
09 *
10 +
11 RCL 10
12 4
13 Y↑X
14 RCL 23
15 *
16 .160505 E-7
17 *
18 +
19 RCL 27
20 -6.61526 E-4
21 *
22 +
23 RCL 10
24 X↑2
25 RCL 24
26 *
27 .16521 E-6
28 *
29 +
30 RCL 23
31 RCL 10
32 *
33 -1.90443 E-4
34 *
35 +
36 RCL 10
37 RCL 24
38 *
39 .993143 E-5
40 *
41 +
42 RCL 24
43 1.21211 E-5
44 *
45 +
46 STO 00
47 4.97996
48 *
49 50.2504
50 +
```

```
51 RCL 29
52 5.72239 E-5
53 *
54 +
55 RCL 00
56 3
57 Y↑X
58 RCL 29
59 *
60 .548313 E-7
61 *
62 +
63 RCL 00
64 4
65 Y↑X
66 RCL 29
67 *
68 -.193279 E-8
69 *
70 +
71 RCL 11
72 3
73 Y↑X
74 -2.29042 E-3
75 *
76 +
77 RCL 11
78 3
79 Y↑X
80 RCL 00
81 X↑2
82 *
83 -2.03324 E-5
84 *
85 +
86 RCL 00
87 X↑2
88 RCL 28
89 *
90 1.96829 E-4
91 *
92 +
93 STO 31
94 .END.
```

K. TORQUE TO HOVER OUT OF GROUND EFFECT

Program Title: OGE

Accuracy: ±1% Q

Upper Chart

Independent Variables:

$A = DA/1000$

$B = GWT/1000$

Relationship: Regression equation with BL as the dependent variable.

Term	Coefficient
Intercept	4.29541
A	-7.98310×10^{-2}
B	-1.29853
A^4B^4	$.765896 \times 10^{-9}$
A^2B^4	$.225432 \times 10^{-6}$
AB^4	$.392898 \times 10^{-5}$
B^2	7.75365×10^{-2}

Lower Chart

Independent Variables:

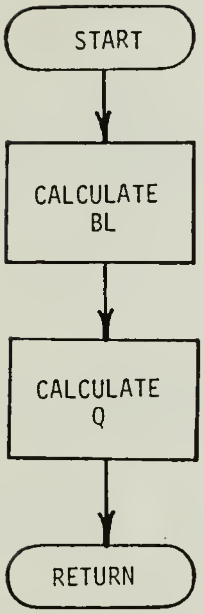
A = Wind

$B = BL$

Relationship: Regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	54.9889
A	$-.152276$
B	5.00758
A^4B^2	$-.137789 \times 10^{-6}$
A^2	-1.70953×10^{-2}
A^2B^2	1.06374×10^{-4}
AB	-1.23812×10^{-2}

OGE



HOGE Q STORED R_{32}

```
01♦LBL "OGE"
02 RCL 10
03 -7.9831 E-2
04 *
05 4.29541
06 +
07 RCL 09
08 -1.29853
09 *
10 +
11 RCL 10
12 4
13 Y↑X
14 RCL 24
15 *
16 .765896 E-9
17 *
18 +
19 RCL 10
20 X↑2
21 RCL 24
22 *
23 .225432 E-6
24 *
25 +
26 RCL 10
27 RCL 24
28 *
29 .392898 E-5
30 *
31 +
32 RCL 22
33 7.75365 E-2
34 *
35 +
36 STO 00
37 5.08758
38 *
39 54.9889
40 +
41 RCL 11
42 -.152276
43 *
44 +
45 RCL 29
46 RCL 00
47 X↑2
48 *
49 -.137789 E-6
50 *
```

```
51 +
52 RCL 28
53 -1.70953 E-2
54 *
55 +
56 RCL 00
57 X↑2
58 RCL 28
59 *
60 1.06374 E-4
61 *
62 +
63 RCL 11
64 RCL 00
65 *
66 -1.23812 E-2
67 *
68 +
69 STO 32
70 .END.
```

L. MAXIMUM RANGE - TWO ENGINES

Program Title: RNG

Accuracy: ±1% KIAS, ±.001 NM/LB

Independent Variables (all three charts):

A = GWT/1000
B = PA/1000

Upper Chart (This chart was not programmed.)

Relationships:

For PA = sea level GWT ≤ 18,000

$$Q = 34.047755\ A^{.262953}$$

For PA = sea level GWT ≥ 18,000

$$Q = 27.175861\ [4.984697 \text{ X } 10^{7}]**A^{-1}$$

For PA = 2000 GWT ≤ 17,000

$$Q = -11.2467 \ln(A) - 29597407\ A^{-6} + .178 \text{ X } 10^{-9} A^{8} + 100.6$$

For PA = 2000 GWT ≥ 17,000

$$Q = 649.485192\ A^{-.792411}$$

For PA = 4000

$$Q = -2.9459\ A - .56081 \text{ X } 10^{9} A^{-7} + .15477 \text{ X } 10^{-9} A^{8} + 110.325$$

For PA = 6000

$$Q = -.151820\ A^{2} - 3402987\ A^{-5} + .635606 \text{ X } 10^{-9}\ A^{8} + 96.4384$$

For PA = 8000

$$Q = -.227207\ A^{2} - 4646405\ A^{-5} + .146173 \text{ X } 10^{-8}\ A^{8} + 107.055$$

For PA =10,000

$$Q = -79.9623\ A**A^{-1} + .803736 \text{ X } 10^{9}\ A^{-7} + 138.181$$

Middle Chart

Relationships:

For PA = sea level GWT ≥ 18,000

$$CAS = [4.16747 \text{ X } 10^{-5}(A - 14.1227)^2 + 7.11631 \text{ X } 10^{-3}]^{-1}$$

For PA = sea level GWT ≤ 18,000

$$CAS = [7.19502 \text{ X } 10^{-6}(A - 13.4511)^2 + 7.60263 \text{ X } 10^{-3}]^{-1}$$

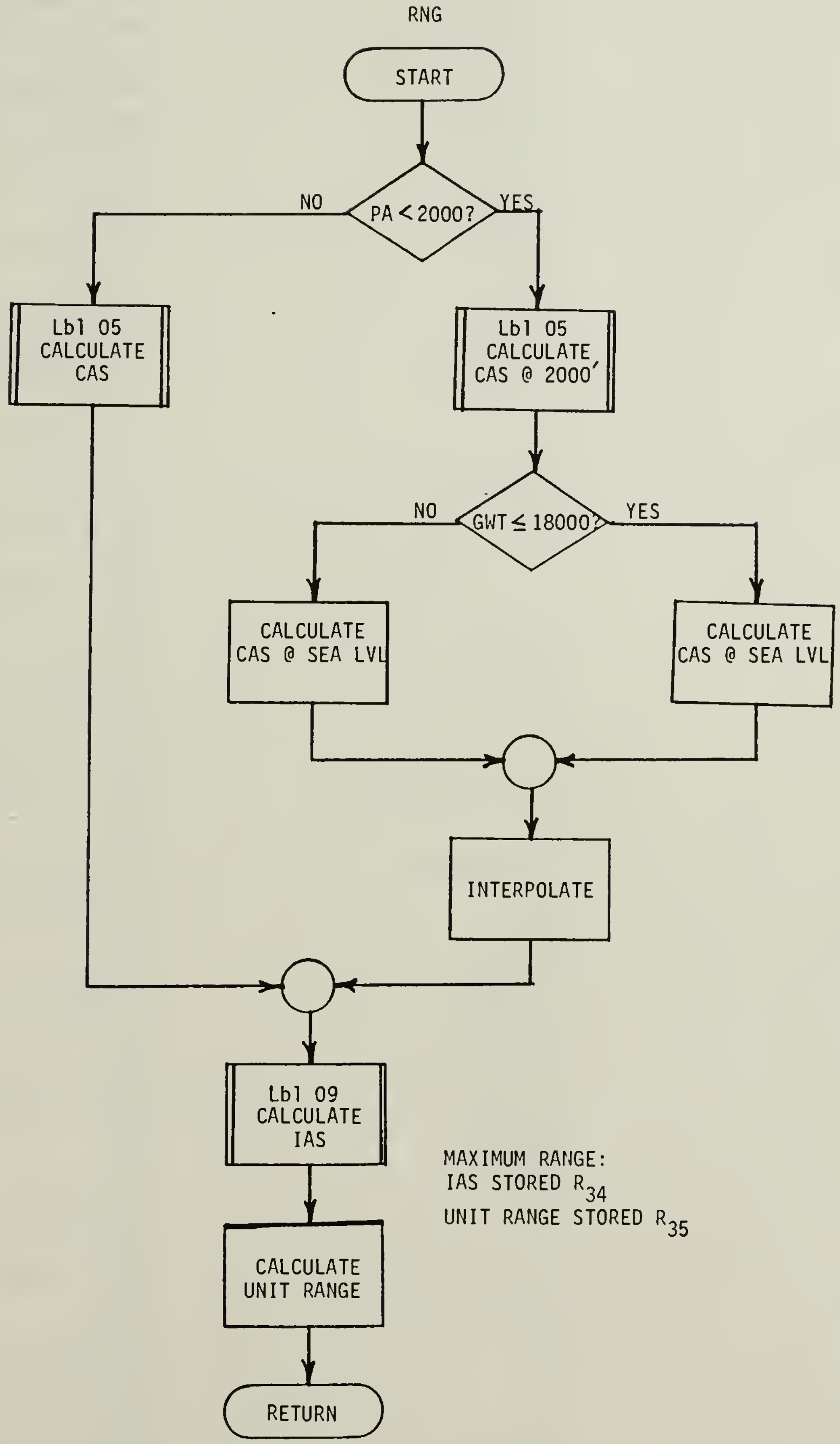
Remainder of chart is regression equation with CAS as the dependent variable.

Term	Coefficient
Intercept	86.8528
A	4.55657
A^4	$-4.02861 \text{ X } 10^{-4}$
A^4B	$1.18176 \text{ X } 10^{-4}$
A^3B	$-2.64073 \text{ X } 10^{-3}$
A^2B^2	$-6.85829 \text{ X } 10^{-3}$
AB^2	.103665
AB^4	$5.71337 \text{ X } 10^{-4}$
B^4	$-9.58130 \text{ X } 10^{-3}$

Lower Chart

Relationship: Regression equation with Unit Range as the dependent variable.

Term	Coefficient
Intercept	.117152
B	$-8.62852 \text{ X } 10^{-3}$
A^4B	$-.577580 \text{ X } 10^{-7}$
A^4B^3	$-.108601 \text{ X } 10^{-8}$
A^2	$-5.26033 \text{ X } 10^{-5}$
A^2B^2	$-.648423 \text{ X } 10^{-6}$
A^2B^3	$.412269 \text{ X } 10^{-6}$
AB	$9.71483 \text{ X } 10^{-4}$
AB^4	$-.162898 \text{ X } 10^{-6}$



MAXIMUM RANGE:
IAS STORED R_{34}
UNIT RANGE STORED R_{35}

```
01♦LBL "RNG"
02 2
03 RCL 08
04 X<Y?
05 GTO 03
06 SF 03
07♦LBL 05
08 RCL 24
09 RCL 08
10 *
11 1.18176 E-4
12 *
13 86.8528
14 +
15 RCL 24
16 -4.02861 E-4
17 *
18 +
19 RCL 09
20 4.55657
21 *
22 +
23 RCL 23
24 RCL 08
25 *
26 -2.64073 E-3
27 *
28 +
29 RCL 22
30 RCL 18
31 *
32 -6.85829 E-3
33 *
34 +
35 RCL 09
36 RCL 18
37 *
38 .103665
39 *
40 +
41 RCL 09
42 RCL 20
43 *
44 5.71337 E-4
45 *
46 +
47 RCL 20
48 -9.5813 E-3
49 *
50 +
51 FS?C 03
52 GTO 09
53 STO 34
54 RTN
55♦LBL 03
56 STO 06
57 X<>Y
58 STO 08
59 XEQ 06
60 XEQ 05
61 18
62 RCL 09
63 X<=Y?
64 GTO 04
65 -14.1227
66 +
67 X↑2
68 4.16747 E-5
69 *
70 7.11631 E-3
71 +
72 1/X
73 GTO 07
74♦LBL 04
75 -13.4511
76 +
77 X↑2
78 7.19502 E-6
79 *
80 7.60263 E-3
81 +
82 1/X
83♦LBL 07
84 ENTER↑
85 ENTER↑
86 RCL 06
87 STO 08
88 ENTER↑
89 XEQ 06
90 RDN
91 2
92 /
93 X<>Y
94 RCL 34
95 -
96 *
97 CHS
98 +
99♦LBL 09
100 1.03581
101 *
102 5.530087
103 -
104 STO 34
105 GTO 08
106♦LBL 06
107 X↑2
108 STO 18
109 X↑2
110 STO 20
111 RTN
112♦LBL 08
113 RCL 08
114 -8.62852 E-3
115 *
116 .117152
117 +
118 RCL 24
119 RCL 08
120 *
121 -.57758 E-7
122 *
123 +
124 RCL 24
125 RCL 19
126 *
127 -.108601 E-8
128 *
129 +
130 RCL 22
131 -5.26033 E-5
132 *
133 +
134 RCL 22
135 RCL 18
136 *
137 -.648423 E-6
138 *
139 +
140 RCL 22
141 RCL 19
142 *
143 .412269 E-6
144 *
145 +
146 RCL 09
147 RCL 08
148 *
149 9.71483 E-4
150 *
```

```
151 +
152 RCL 09
153 RCL 20
154 *
155 -.162898 E-6
156 *
157 +
158 STO 35
159 RTN
160 .END.
```

M. MAXIMUM ENDURANCE - TWO ENGINES

Program Title: ENDR

Accuracy: ±1 KIAS, ±10 LB/HR (valid only for $PA \leq 6000$)

Independent Variables (all three charts):

$A = GWT/1000$

$B = PA/1000$

Upper Chart

Relationship: Regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	2.16247
A	2.34699
A^3B	1.39390×10^{-4}
A^6B^6	$.341286 \times 10^{-12}$
A^5B^6	$-.564025 \times 10^{-11}$
A^6B	$.572765 \times 10^{-7}$
A^5B	$-.143151 \times 10^{-5}$

Middle Chart

Relationships:

For $PA = 6000$ $\quad GWT \geq 20{,}750$

$CAS = -7.00\ A + 214.25$

Remainder of chart is regression equation with CAS as the dependent variable.

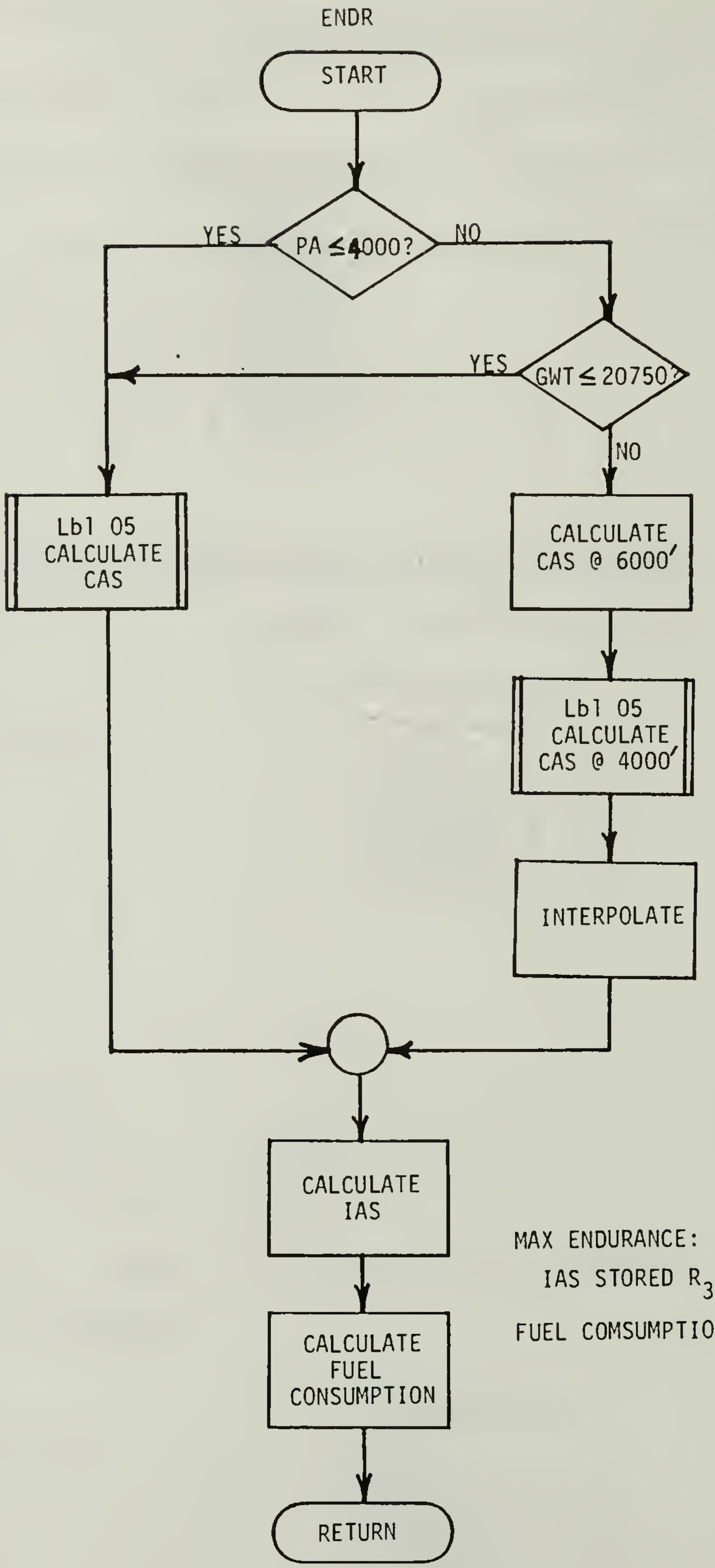
Term	Coefficient
Intercept	38.5672
A	1.21284
A^4	2.86275×10^{-5}
A^3B^2	-2.73779×10^{-5}
A^6B^6	$-.474676 \times 10^{-12}$
A^5B^4	$.168795 \times 10^{-8}$
A^6B	$-.958807 \times 10^{-7}$
A^6B^2	$-.470741 \times 10^{-8}$
A^5B	$.270604 \times 10^{-5}$
A^{-2}	217.383
$B^{.5}$	-.496303

Bottom Chart

Relationship: Regression equation with Fuel Consumption / 100 as the dependent variable.

Term	Coefficient
Intercept	6.19995
A	.103193
B	-.226709
A^4B^2	$.780189 \times 10^{-7}$
A^4B^4	$.188099 \times 10^{-8}$
A^3	2.08597×10^{-4}
A^3B^3	$-.773409 \times 10^{-6}$
A^2B^2	7.46164×10^{-5}
B^2	4.87393×10^{-3}

Note: This program and curve/surface fits for all three charts are only valid for $PA \leq 6000$.



MAX ENDURANCE:

IAS STORED R_{36}

FUEL COMSUMPTION STORED R_{37}

```
01♦LBL "ENDR"
02 GTO 02
03♦LBL 10
04 STO 00
05 X<>Y
06 ENTER↑
07 ENTER↑
08 ENTER↑
09 X↑2
10♦LBL 11
11 STO IND 00
12 *
13 ISG 00
14 GTO 11
15 RTN
16♦LBL 02
17 4
18 RCL 08
19 X<=Y?
20 GTO 05
21 20.75
22 RCL 09
23 X<=Y?
24 GTO 05
25 X<> Z
26 STO 06
27 R↑
28 STO 08
29 -
30 2
31 /
32 STO 05
33 18.021
34 XEQ 10
35 STO 21
36 RCL 09
37 -7
38 *
39 214.25
40 +
41 XEQ 06
42 ENTER↑
43 X<> Z
44 -
45 RCL 65
46 *
47 -
48 GTO 08
49♦LBL 05
50 SF 03
```

```
51♦LBL 06
52 RCL 09
53 1.21284
54 *
55 38.5672
56 +
57 RCL 24
58 2.86275 E-5
59 *
60 +
61 RCL 23
62 RCL 18
63 *
64 -2.73779 E-5
65 *
66 +
67 RCL 26
68 RCL 21
69 *
70 -.474626 E-12
71 *
72 +
73 RCL 25
74 RCL 20
75 *
76 .168795 E-8
77 *
78 +
79 RCL 26
80 RCL 08
81 *
82 -.958807 E-7
83 *
84 +
85 RCL 26
86 RCL 18
87 *
88 -.470741 E-8
89 *
90 +
91 RCL 25
92 RCL 08
93 *
94 .270604 E-5
95 *
96 +
97 RCL 22
98 1/X
99 217.383
100 *
```

```
101 +
102 RCL 08
103 SQRT
104 -.496303
105 *
106 +
107 FS? 03
108 GTO 08
109 RTN
110♦LBL 08
111 1.03581
112 *
113 5.53
114 -
115 STO 36
116 FC?C 03
117 GTO 09
118 GTO 03
119♦LBL 09
120 RCL 06
121 STO 08
122 18.021
123 XEQ 10
124 STO 21
125♦LBL 03
126 RCL 09
127 .103193
128 *
129 6.19995
130 +
131 RCL 08
132 -.226709
133 *
134 +
135 RCL 24
136 RCL 18
137 *
138 .780189 E-7
139 *
140 +
141 RCL 24
142 RCL 20
143 *
144 .188099 E-8
145 *
146 +
147 RCL 23
148 2.08597 E-4
149 *
150 +
151 RCL 23
152 RCL 19
153 *
154 -.773409 E-6
155 *
156 +
157 RCL 22
158 RCL 18
159 *
160 7.46164 E-5
161 *
162 +
163 RCL 18
164 4.87393 E-3
165 *
166 +
167 100
168 *
169 STO 37
170. .END.
```

N. ABILITY TO MAINTAIN FLIGHT - ONE ENGINE

Program Title: ENVLP

Accuracy: ±1 KIAS (valid only for GWT ≥ 15,875)

Independent Variables:

$A = DA/1000$

$B = GWT/1000$

$C = Q/10$

Upper Chart

Relationship: Regression equation with BL as the dependent variable.

Term	Coefficient
Intercept	13.1709
B	3.24579
A^4B^4	$.384129 \times 10^{-7}$
A^3B	1.69462×10^{-3}
A^3B^3	-2.75020×10^{-5}
A^3B^4	$.808802 \times 10^{-6}$
A^2B^3	2.41848×10^{-5}
B^2	5.11714×10^{-2}

Lower Chart

The influence lines were curve fit individually and are identified as being above the baseline (Vmax) or below the baseline (Vmin) and corresponding to a GWT influence line in the upper chart. All the lower chart influence lines have the form

$$KIAS = 10[(a + c\,C + e\,C^2 + g\,C^3)/(1 + b\,C + d\,C^2 + f\,C^3)]$$

Vmax

GWT	a	b	c	d
14,000	205.106051	-3.172488	-52.767525	.136842
16,000	15.366945	-.343431	6.089327	-.080259
18,000	158.178056	-.195222	-23.152448	-.181632
20,000	377.359873	-4.019234	-71.947887	.130297
21,000	142040.814	-1559.5132	648.6062	-220.3889

GWT	e	f	g
14,000	-3.096207	.047131	.952305
16,000	-3.234997	.014180	.284553
18,000	-2.229709	.021735	.320453
20,000	-2.795544	.028567	.639954
21,000	-8747.8908	36.399824	714.013828

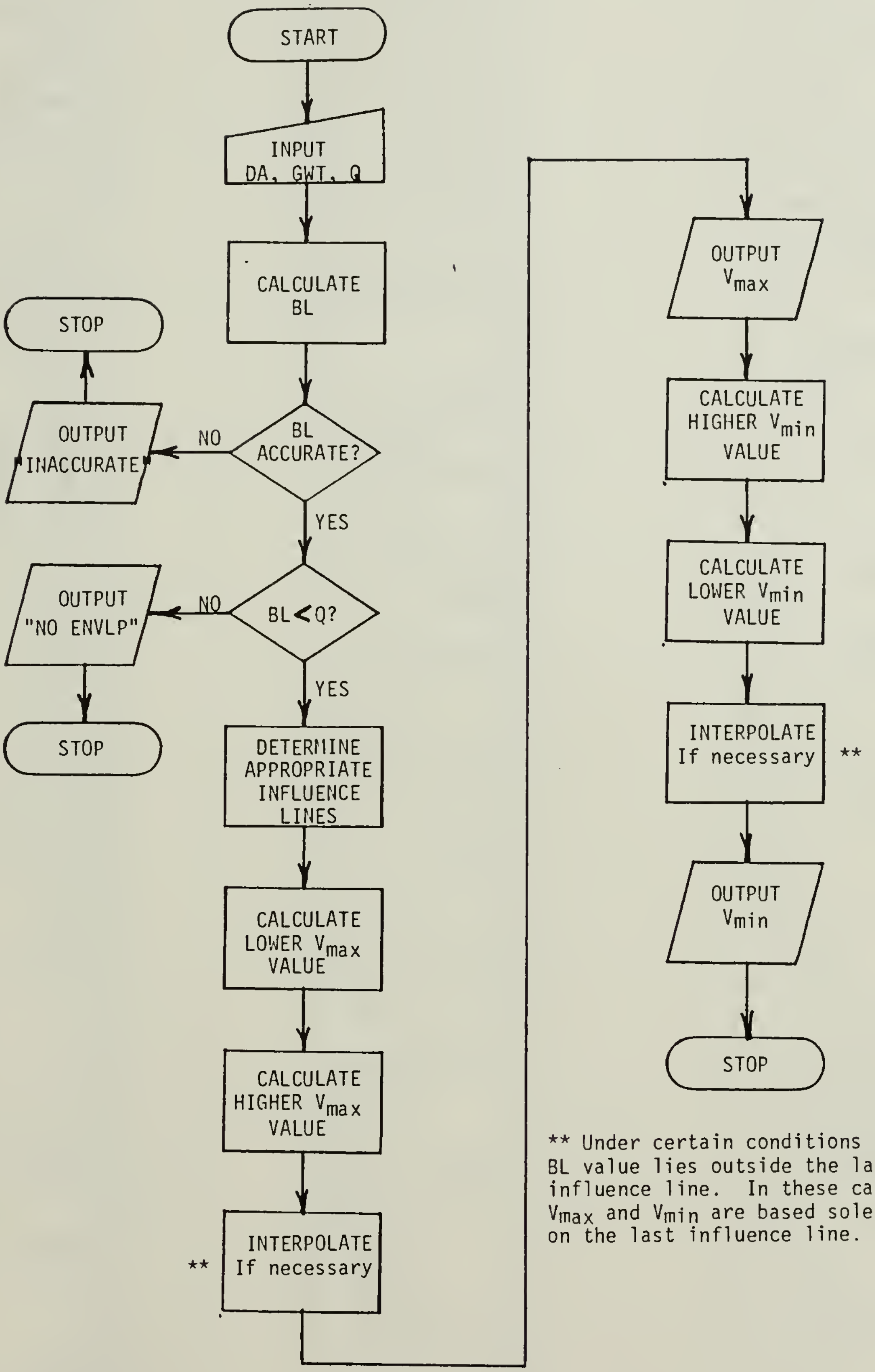
Vmin

GWT	a	b	c	d
14,000	-561.206728	-20.296937	-102.617993	1.262022
16,000	.269674	1.745743	-12.269365	-.715187
18,000	142.721580	-.530094	-51.367270	-.101086
20,000	637.457451	3.703332	-133.209123	-.453900
21,000	208.927822	-.861527	-51.818192	.159518

GWT	e	f	g
14,000	48.308383	.259697	-3.033215
16,000	2.140345	.061489	-.069948
18,000	5.645454	.017929	-.180476
20,000	9.038421	.006561	-.213890
21,000	4.405128	-.008074	-.128883

Note: Although the curve fits for the entire figure are accurate (except as noted on the figure itself), the program ENVLP is valid only for GWT ≥ 15,875.

ENVLP


START
INPUT DA, GWT, Q
CALCULATE BL
BL ACCURATE?
NO
OUTPUT "INACCURATE"
STOP
YES
BL < Q?
NO
OUTPUT "NO ENVLP"
STOP
YES
DETERMINE APPROPRIATE INFLUENCE LINES
CALCULATE LOWER V_{max} VALUE
CALCULATE HIGHER V_{max} VALUE
** INTERPOLATE If necessary
OUTPUT V_{max}
CALCULATE HIGHER V_{min} VALUE
CALCULATE LOWER V_{min} VALUE
INTERPOLATE If necessary **
OUTPUT V_{min}
STOP

** Under certain conditions the BL value lies outside the last influence line. In these cases V_{max} and V_{min} are based solely on the last influence line.

```
01♦LBL "ENVLP"
02 0
03 X<>F
04 FIX 0
05 "DA ?  "
06 40
07 XTOA
08 "⊦FT"
09 41
10 XTOA
11 PROMPT
12 1000
13 /
14 STO 10
15 3
16 Y↑X
17 STO 27
18 "GWT ?  "
19 40
20 XTOA
21 "⊦LB"
22 41
23 XTOA
24 PROMPT
25 1000
26 /
27 STO 09
28 22.024
29 XEQ 07
30 "Q ?  "
31 40
32 XTOA
33 "⊦%"
34 41
35 XTOA
36 PROMPT
37 STO 38
38 GTO 01
39♦LBL 07
40 STO 00
41 X<>Y
42 ENTER↑
43 ENTER↑
44 X↑2
45♦LBL 08
46 STO IND 00
47 *
48 ISG 00
49 GTO 08
50 RTN
51♦LBL 01
52 RCL 09
53 3.24579
54 *
55 13.1709
56 +
57 RCL 10
58 4
59 Y↑X
60 RCL 24
61 *
62 .384129 E-7
63 *
64 +
65 RCL 27
66 RCL 09
67 *
68 1.69462 E-3
69 *
70 +
71 RCL 27
72 RCL 23
73 *
74 -2.7502 E-5
75 *
76 +
77 RCL 27
78 RCL 24
79 *
80 .808802 E-6
81 *
82 +
83 RCL 10
84 X↑2
85 RCL 23
86 *
87 2.41848 E-5
88 *
89 +
90 RCL 22
91 5.11714 E-2
92 *
93 +
94 10
95 /
96 STO 14
97 RCL X
98 LN
99 -19.56
100 *
101 52.415
102 +
103 RCL 10
104 X>Y?
105 GTO 18
106 RCL Z
107 RCL 38
108 10
109 /
110 STO 13
111 X<=Y?
112 GTO 05
113 XEQ 21
114 XEQ 20
115 .575
116 STO 07
117 000.003
118 RCL 14
119♦LBL 04
120 RCL IND Y
121 X>Y?
122 GTO 15
123 SF 01
124 RDN
125 ISG Y
126 GTO 04
127 GTO 16
128♦LBL 15
129 FC?C 01
130 GTO 18
131 RCL 13
132 X<=Y?
133 XEQ 12
134 FC? 03
135 RDN
136 -
137 CHS
138 4
139 ST+ Z
140 RDN
141 RCL IND Y
142 /
143 STO 07
144 RDN
145 18
146 +
147 STO 12
148♦LBL 14
149 XEQ IND 12
150 XEQ 20
```

```
151 XEQ "FIT"
152 FS? 03
153 XEQ 11
154 STO 14
155 1
156 ST- 12
157 XEQ IND 12
158 XEQ 20
159 XEQ "FIT"
160 RCL 14
161 -
162 RCL 07
163 *
164 RCL 14
165 +
166 10
167 *
168 FS? 02
169 GTO 03
170 XEQ 02
171 FC? 03
172 GTO 13
173 RCL 13
174 STO 14
175 RCL 40
176 STO 13
177◆LBL 13
178 6
179 ST+ 12
180 GTO 14
181◆LBL 10
182 6.875
183 R↑
184 +
185 X<> 14
186 GTO 09
187◆LBL 11
188 RCL 13
189 STO 40
190 RCL 14
191 STO 13
192 RCL Z
193 RTN
194◆LBL 12
195 X<>Y
196 RDN
197 -
198 CHS
199 ENTER↑
200 R↑
```

```
201 +
202 STO 13
203 RCL Z
204 INT
205 X=0?
206 GTO 10
207 1
208 -
209 RCL IND X
210 R↑
211 +
212 X<> 14
213 X<>Y
214 1
215 +
216 X<>Y
217◆LBL 09
218 RCL IND Y
219 SF 03
220 RTN
221◆LBL 16
222 SF 04
223 R↑
224 -
225 STO 14
226 XEQ 25
227 XEQ 20
228 XEQ "FIT"
229 RCL 14
230 -
231 10
232 *
233◆LBL 02
234 TONE 0
235 "VMAX= "
236 ARCL X
237 "⊢ KT"
238 PROMPT
239 FS? 04
240 GTO 17
241 SF 02
242 RTN
243◆LBL 17
244 XEQ 30
245 XEQ 20
246 XEQ "FIT"
247 RCL 14
248 +
249 10
250 *
```

```
251◆LBL 03
252 TONE 0
253 "VMIN= "
254 ARCL X
255 "⊢ KT"
256 PROMPT
257 GTO 06
258◆LBL 05
259 TONE 0
260 "NO ENVLP"
261 PROMPT
262 GTO 06
263◆LBL 18
264 TONE 0
265 "INACCURATE"
266 PROMPT
267◆LBL 06
268 0
269 X<>F
270 FIX 4
271 STOP
272 GTO "ENVLP"
273◆LBL 21
274 1.05
275 1.075
276 .875
277 XEQ 19
278 10.45
279 9.875
280 8.825
281 7.75
282 RTN
283◆LBL 22
284 .284553
285 .01418
286 -3.234997
287 XEQ 19
288 -.080259
289 6.089327
290 -.343431
291 15.366945
292 RTN
293◆LBL 23
294 .320453
295 .021735
296 -2.229709
297 XEQ 19
298 -.181632
299 -23.152448
300 -.195222
```

```
301 158.178056
302 RTN
303♦LBL 24
304 .639954
305 .028567
306 -2.795544
307 XEQ 19
308 .130297
309 -71.947887
310 -4.019234
311 377.359873
312 RTN
313♦LBL 25
314 714.013828
315 36.399824
316 -8747.890785
317 XEQ 19
318 -220.3889
319 648.606162
320 -1559.51316
321 142040.814
322 RTN
323♦LBL 27
324 -.069948
325 .061489
326 2.140345
327 XEQ 19
328 -.715187
329 -12.269365
330 1.745743
331 .269674
332 RTN
333♦LBL 28
334 -.100476
335 .017929
336 5.645454
337 XEQ 19
338 -.101886
339 -51.36727
340 -.530094
341 142.72158
342 RTN
343♦LBL 29
344 -.21389
345 .006561
346 9.038421
347 XEQ 19
348 -.4539
349 -133.209123
350 3.703332
351 637.457451
352 RTN
353♦LBL 30
354 -.128883
355 -.008074
356 4.405128
357 XEQ 19
358 .159518
359 -51.818192
360 -.861527
361 200.927822
362 RTN
363♦LBL 19
364 STO 04
365 RDN
366 STO 05
367 RDN
368 STO 06
369 RTN
370♦LBL 20
371 STO 00
372 RDN
373 STO 01
374 RDN
375 STO 02
376 RDN
377 STO 03
378 RTN
379♦LBL "FIT"
380 RCL 13
381 3
382 Y↑X
383 ENTER↑
384 ENTER↑
385 RCL 06
386 *
387 RCL 13
388 X↑2
389 RCL 04
390 *
391 +
392 RCL 13
393 RCL 02
394 *
395 +
396 RCL 00
397 +
398 RCL Y
399 RCL 05
400 *
401 RCL 13
402 X↑2
403 RCL 03
404 *
405 +
406 RCL 13
407 RCL 01
408 *
409 +
410 1
411 +
412 /
413 RTN
414 .END.
```

O. MAXIMUM RANGE - ONE ENGINE

Program Title: SE RNG

Accuracy: ±1 KIAS, ±.001 NM/LB (valid only for PA $\leq$ 6000)

Independent Variables (all three charts):

A = GWT/1000

B = PA/1000

C = GWT/10,000

Upper Chart (This chart was not programmed.)

Relationship: Regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	108.555
B	-2.90288
B^3	1.66076×10^{-2}
B^4	-1.41413×10^{-3}

Middle Chart

Relationship: All influence lines are of the form

$$KCAS = [(a + c A + e A^2 + g A^3)/(1 + b A + d A^2 + f A^3)]$$

PA	a	b	c	d
S.L.	502.369992	.362933	-23.349262	.005277
2000	17512562.0	-760.134361	-3460915.51	-420.662981
4000	-225.872732	1.343442	237.964440	-.112237
6000	6009.210952	5.758043	316.015707	.297525
8000	139.362855	19.800377	141.568193	4.417058
10000	371.074536	.117628	-22.090544	-.000925

PA	e	f	g
S.L.	4.550521	-.000784	-.182846
2000	167590.8365	21.738883	-2020.284589
4000	-19.841131	.002110	.423841
6000	-4.695139	-.032069	-1.546168
8000	-51.565799	-8.730509	-39.644607
10000	.575690	-.000568	-.034429

Bottom Chart

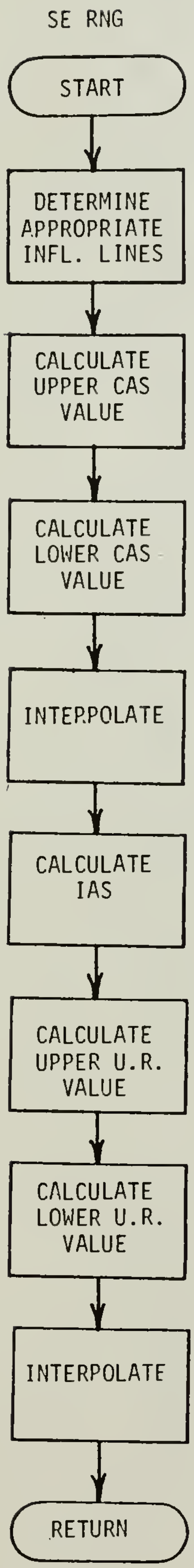
Relationship: All influence lines are of the form

$$UR = (a + c\,C + e\,C^2 + g\,C^3)/[10(1 + b\,C + d\,C^2 + f\,C^3)]$$

PA	a	b	c	d
S.L.	.925295	-1.486832	-1.178663	.899270
2000	1384.426869	8105.208102	9968.662342	-7100.218382
4000	-212.048697	-125.637807	227.277663	158.955307
6000	-204.717059	-151.075119	173.057337	196.856137
8000	9.078675	-4.835348	-25.043409	2.721607
10000	67.098651	23.295696	-8.710976	20.183821

PA	e	f	g
S.L.	.682470	-.194762	-.153230
2000	-9863.619555	1539.514953	2283.614306
4000	-28.112574	-48.228909	-16.375874
6000	40.296510	-61.780622	-39.330057
8000	17.309474	-.179344	-3.425753
10000	10.733731	-20.628002	-17.839002

Note: Although the curve fits are accurate for PA ≤ 10,000 on each of these three charts, the program SE RNG was written and is valid only for PA ≤ 6000.


SE RNG
START
DETERMINE APPROPRIATE INFL. LINES
CALCULATE UPPER CAS VALUE
CALCULATE LOWER CAS VALUE
INTERPOLATE
CALCULATE IAS
CALCULATE UPPER U.R. VALUE
CALCULATE LOWER U.R. VALUE
INTERPOLATE
RETURN

S/E MAX RANGE:
IAS STORED R_{40}
UNIT RANGE STORED R_{41}

```
01♦LBL "SE RHO"
02 RCL 09
03 STO 13
04 2.00602
05 STO 12
06♦LBL 05
07 RCL 12
08 INT
09 RCL 08
10 X<=Y?
11 GTO 07
12 ISG 12
13 GTO 05
14 GTO 08
15♦LBL 07
16 -
17 2
18 /
19 STO 14
20 XEQ IND 12
21 XEQ 11
22 XEQ "FIT"
23 STO 40
24 2
25 ST- 12
26 XEQ IND 12
27 XEQ 11
28 XEQ "FIT"
29 RCL X
30 RCL 40
31 -
32 RCL 14
33 *
34 RCL 40
35 +
36 1.03581
37 *
38 5.53
39 -
40 STO 40
41 GTO 13
42♦LBL 08
43 999
44 STO 40
45 STO 41
46 RTN
47♦LBL 11
48 STO 00
49 RDN
50 STO 01
51 RDN
52 STO 02
53 RDN
54 STO 03
55 RTN
56♦LBL 00
57 -.183
58 -7.84 E-4
59 4.55
60 XEQ 09
61 5.277 E-3
62 -23.35
63 .3629
64 502
65 RTN
66♦LBL 02
67 -2020.3
68 21.74
69 1676 E2
70 XEQ 09
71 -420.66
72 -3461 E3
73 -760
74 175126 E2
75 RTN
76♦LBL 04
77 .42384
78 2.11 E-3
79 -19.84
80 XEQ 09
81 -.1122
82 238
83 1.3474
84 -226
85 RTN
86♦LBL 06
87 -1.5462
88 -.03207
89 -4.695
90 XEQ 09
91 .2975
92 316
93 5.758
94 6009
95 RTN
96♦LBL 13
97 10
98 ST/ 13
99 12
100 ST+ 12
101 XEQ IND 12
102 XEQ 11
103 XEQ "FIT"
104 STO 41
105 2
106 ST- 12
107 XEQ IND 12
108 XEQ 11
109 XEQ "FIT"
110 RCL 41
111 -
112 RCL 14
113 *
114 ST+ 41
115 10
116 ST/ 41
117 RTN
118♦LBL 10
119 -.15323
120 -.1948
121 .6825
122 XEQ 09
123 .8993
124 -1.179
125 -1.487
126 .9253
127 RTN
128♦LBL 12
129 2283.614
130 1539.5
131 -9863.6
132 XEQ 09
133 -7100
134 9969
135 8105
136 1384.4
137 RTN
138♦LBL 14
139 -16.376
140 -48.229
141 -28.113
142 XEQ 09
143 158.955
144 227.28
145 -125.674
146 -212.05
147 RTN
148♦LBL 16
149 -39.33
150 -61.78
```

```
151 40.2965
152 XEQ 09
153 196.856
154 173.057
155 -151.075
156 -204.717
157 RTN
158♦LBL 09
159 STO 04
160 RDN
161 STO 05
162 RDN
163 STO 06
164 RTN
165 .END.
```

P. MAXIMUM ENDURANCE - ONE ENGINE

Program Title: SE ENDR

Accuracy: ±1 KIAS, ±10 LB/HR

Independent Variables:

A = GWT/1000

B = PA/1000

C = GWT/10,000

Upper Chart

Relationship: Regression equation with Q as the dependent variable.

Term	Coefficient
Intercept	-51.2108
A	10.8546
A^4B^3	$-.104315 \text{ X } 10^{-6}$
A^4B^4	$.851402 \text{ X } 10^{-8}$
A^2	-.167166
A^2B^2	$1.10126 \text{ X } 10^{-4}$
AB	$-1.96415 \text{ X } 10^{-3}$
B^4	$-1.12832 \text{ X } 10^{-4}$

Middle Chart

Relationship: Regression equation with CAS as the dependent variable.

Term	Coefficient
Intercept	83.4630
AB^3	$-1.56384 \text{ X } 10^{-4}$
A^6	$.895430 \text{ X } 10^{-7}$
A^6B	$-.221193 \text{ X } 10^{-8}$
AB^6	$.720428 \text{ X } 10^{-7}$
A^{-2}	-2818.02
$B**B^{-1}$	-8.27505

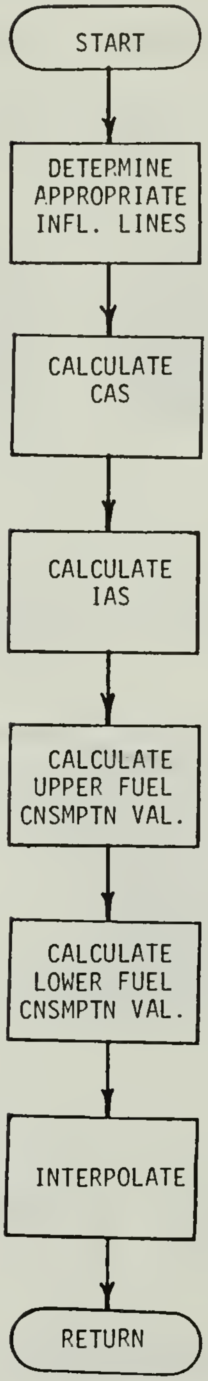
Bottom Chart

Relationship: All influence lines are of the form

$$\text{Fuel Consumption} = 1000[a \exp(b\ C) + c \exp(d\ C)]$$

PA	a	b	c	d
S.L.	.767279	.434063	-.418050	.449000
2000	3.671098	.378791	-3.357889	.369855
4000	.947504	.501061	-.658054	.500161
6000	-31.000000	-270.000000	.252300	.580124
8000	-31.327759	-269.600916	.236572	.611284
10000	.835295	.916064	-.678990	.922650

SE ENDR


START
DETERMINE APPROPRIATE INFL. LINES
CALCULATE CAS
CALCULATE IAS
CALCULATE UPPER FUEL CNSMPTN VAL.
CALCULATE LOWER FUEL CNSMPTN VAL.
INTERPOLATE
RETURN

S/E MAX ENDURANCE:
IAS STORED R_{42}
FUEL CONSUMPTION STORED R_{43}

```
01♦LBL "SE ENDR"
02 2.01002
03 STO 06
04 RCL 08
05♦LBL 15
06 RCL 06
07 INT
08 X>Y?
09 GTO 05
10 RDN
11 SF 01
12 ISG 06
13 GTO 15
14 R↑
15 STO 06
16♦LBL 05
17 -
18 2
19 /
20 STO 07
21 FC?C 01
22 GTO 07
23♦LBL 18
24 RCL 09
25 RCL 19
26 *
27 -1.56384 E-4
28 *
29 83.463
30 +
31 RCL 26
32 .89543 E-7
33 *
34 +
35 RCL 26
36 RCL 08
37 *
38 -.221193 E-8
39 *
40 +
41 RCL 09
42 RCL 21
43 *
44 .720428 E-7
45 *
46 +
47 RCL 22
48 1/X
49 -2818.02
50 *
51 +
52 RCL 08
53 RCL 08
54 1/X
55 Y↑X
56 -8.27505
57 *
58 +
59 FS?C 02
60 RTN
61♦LBL 09
62 1.03581
63 *
64 5.53
65 -
66 STO 42
67 GTO 11
68♦LBL 03
69 STO 08
70 3
71 Y↑X
72 STO 19
73 X↑2
74 STO 21
75 RTN
76♦LBL 07
77 SF 02
78 RCL 08
79 STO 14
80 2
81 XEQ 03
82 XEQ 18
83 RCL X
84 RCL 09
85 .0341
86 *
87 E↑X
88 35.9739
89 *
90 -
91 RCL 07
92 *
93 +
94 RCL 14
95 XEQ 03
96 RDN
97 GTO 09
98♦LBL 11
99 XEQ IND 06
100 XEQ 13
101 XEQ 14
102 STO 05
103 2
104 ST- 06
105 XEQ IND 06
106 XEQ 13
107 XEQ 14
108 RCL 05
109 -
110 RCL 07
111 *
112 RCL 05
113 -
114 1 E3
115 *
116 CHS
117 STO 43
118 RTN
119♦LBL 13
120 STO 03
121 RDN
122 STO 02
123 RDN
124 STO 01
125 RDN
126 STO 00
127 RTN
128♦LBL 14
129 RCL 01
130 RCL 09
131 10
132 /
133 STO 12
134 *
135 E↑X
136 RCL 00
137 *
138 RCL 03
139 RCL 12
140 *
141 E↑X
142 RCL 02
143 *
144 +
145 RTN
146♦LBL 00
147 .767279
148 .434063
149 -.41805
150 .449
```

```
151 RTN
152♦LBL 02
153 3.671098
154 .378791
155 -3.357889
156 .369855
157 RTN
158♦LBL 04
159 .947504
160 .501061
161 -.658054
162 .500161
163 RTN
164♦LBL 06
165 -31
166 -270
167 .2523
168 .500124
169 RTN
170♦LBL 08
171 -31.327759
172 -269.6
173 .236572
174 .611284
175 RTN
176♦LBL 10
177 .835295
178 .916064
179 -.67899
180 .92265
181 RTN
182 .END.
```

Q. GROUND ROLL - POWER OFF

Program Title: ROLL

Accuracy: ±10 FT

Upper Left Chart

This chart is a modified version of the Density Altitude chart. The relationships developed for the Density Altitude chart are valid for this chart, also.

Upper Right Chart

Independent Variables:

$A = DA/1000$

$B = GWT/1000$

Relationship: Regression equation with BL as the dependent variable.

Term	Coefficient
Intercept	6.25495
A	.130801
AB^4	.364592 X 10^{-6}
B^4	-1.47043 X 10^{-5}
A^6	.142700 X 10^{-6}
B^6	.279130 X 10^{-7}
B^{-1}	-67.1310

Lower Chart

Independent Variables:

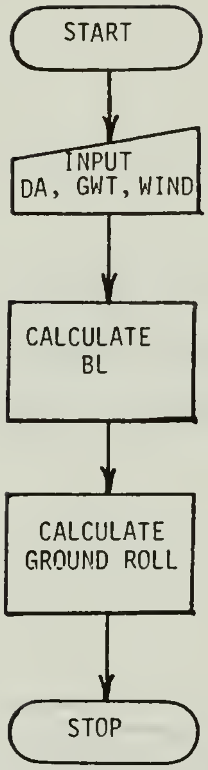
$A = \text{Wind}$

$B = BL$

Relationship: Regression equation with Ground Roll Distance as the dependent variable.

Term	Coefficient
Intercept	1.49721
A	-.121041
B	.500958
A^4	-.839100 X 10^{-6}
A^2	2.01268 X 10^{-3}

ROLL


START
INPUT
DA, GWT, WIND
CALCULATE
BL
CALCULATE
GROUND ROLL
STOP

```
01♦LBL 01
02 "DA ?  "
03 40
04 XTOA
05 "⊦FT"
06 41
07 XTOA
08 PROMPT
09 1000
10 /
11 STO 10
12 "GWT ?  "
13 40
14 XTOA
15 "⊦LB"
16 41
17 XTOA
18 PROMPT
19 1000
20 /
21 STO 09
22 4
23 Y↑X
24 STO 24
25 RCL 09
26 X↑2
27 *
28 STO 26
29 "WIND ?  "
30 40
31 XTOA
32 "⊦KT"
33 41
34 XTOA
35 PROMPT
36 STO 11
37 X↑2
38 STO 28
39 X↑2
40 STO 29
41 XEQ 02
42 FIX 0
43 TONE 0
44 "ROLL= "
45 ARCL X
46 "⊦ FT"
47 PROMPT
48 FIX 4
49 RTN
50♦LBL "ROLL"
51 GTO 01
52♦LBL 02
53 RCL 10
54 .130001
55 *
56 6.25495
57 +
58 RCL 10
59 RCL 24
60 *
61 .364592 E-6
62 *
63 +
64 RCL 24
65 -1.47043 E-5
66 *
67 +
68 RCL 10
69 6
70 Y↑X
71 .1427 E-6
72 *
73 +
74 RCL 26
75 .27913 E-7
76 *
77 +
78 RCL 09
79 1/X
80 -67.131
81 *
82 +
83 .500958
84 *
85 1.49721
86 +
87 RCL 11
88 -.121041
89 *
90 +
91 RCL 29
92 -.8391 E-6
93 *
94 +
95 RCL 28
96 2.01268 E-3
97 *
98 +
99 100
100 *
101 RTN
102 .END.
```

R. MASTER PROGRAM

Program Title: FLIGHT

Accuracy: (not applicable)

Purpose: This program resides in main memory and controls the input, execution, and output of the following programs (residing in extended memory):

DA
E PERF
IGE
OGE
STALL
RNG
ENDR
WTR T/O
SE RNG
SE ENDR
PRINT

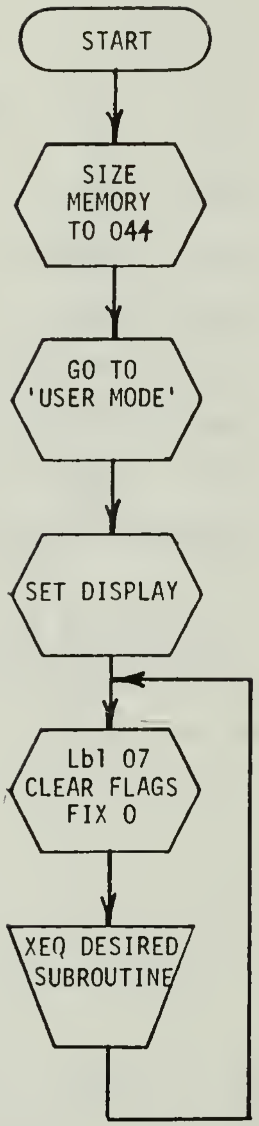
Additionally, through subroutine A (Preflight Planning) and a subordinate program PRINT, this program (FLIGHT) will execute all of the programs listed above in succession, and if a printer is attached, produce a printed output of the results. The subroutines included in this program are:

Subroutine	Corresponding Program
A	PP
a	DA
B	E PERF
C	IGE
c	OGE
D	STALL
E	RNG
e	ENDR

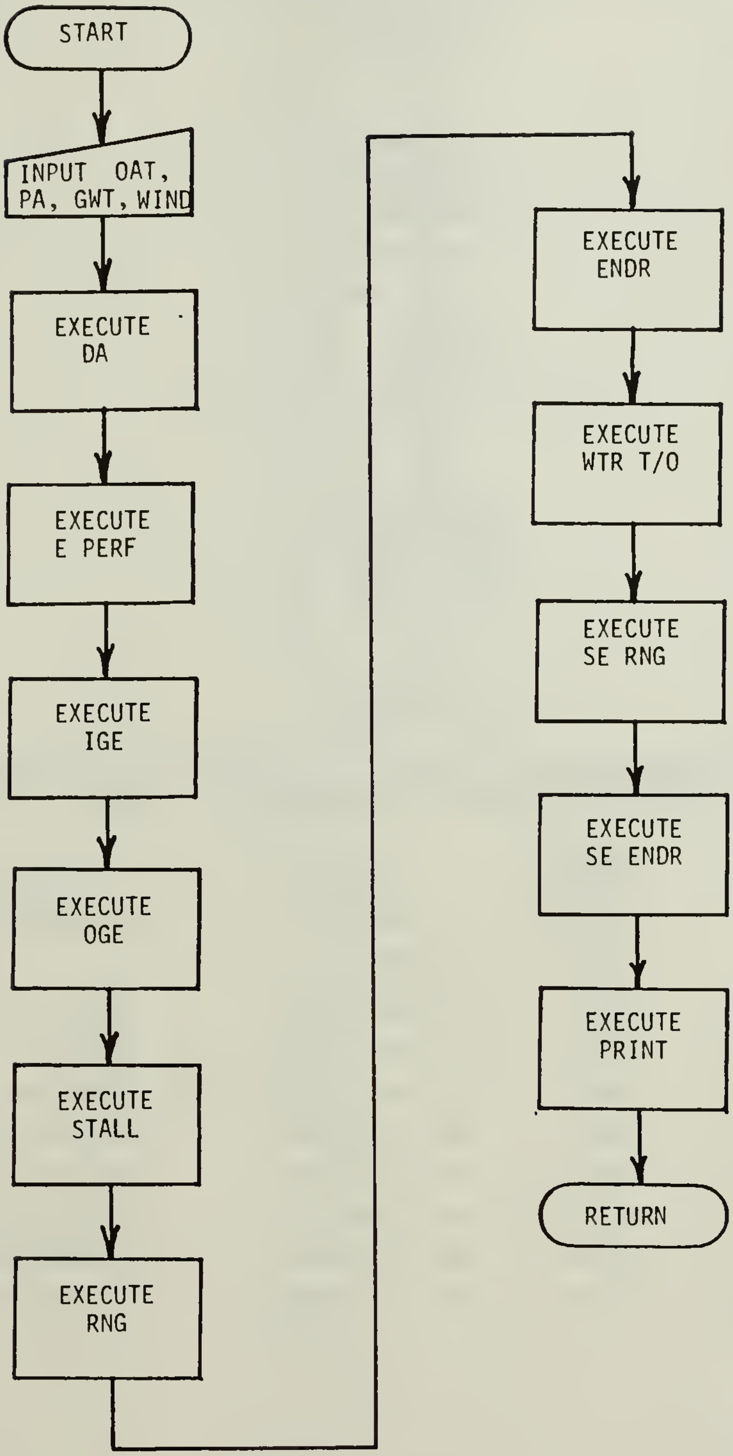
F	WTR T/O
G	SE RNG
H	SE ENDR
01	Input OAT
02	Input PA
03	Input GWT
04	Input Wind
05	Input DA
06	Input Fuel
07	Clear flags, Fix 0
FILL	Load required registers
FIT	Perform function:

$$\frac{a + c X + e X^2 + g X^3}{1 + b X + d X^2 + f X^3}$$

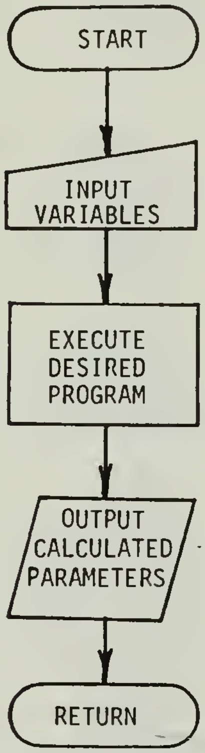
FLIGHT


START
SIZE MEMORY TO 044
GO TO 'USER MODE'
SET DISPLAY
Lbl 07 CLEAR FLAGS FIX 0
XEQ DESIRED SUBROUTINE

FLIGHT Subroutine A



FLIGHT Subroutines a,B,C,c,D,E,e,F,G,H



ALL OF THE NAMED SUBROUTINES HAVE IDENTICAL LOGIC FLOW. ONLY THE INPUT VARIABLES, CALLED PROGRAMS, AND OUTPUT PARAMETERS VARY AS SHOWN IN THE TABLE BELOW.

Subroutine	Program Called	Input	Output
a	DA	PA, OAT	DA, CNV F
B	E PERF	PA, OAT	Q
C	IGE	DA, GWT, WIND	HIGE Q
c	OGE	DA, GWT, WIND	HOGE Q
D	STALL	PA, OAT, Nr, GWT, AOB	STALL IAS
E	RNG	GWT, PA, FUEL	MAX RNG IAS & DIST
e	ENDR	GWT, PA, FUEL	MAX ENDR IAS & TIME
F	WTR T/O	OAT, GWT	WTR T/O IAS
G	SE RNG	GWT, PA, FUEL	SE MAX RNG IAS & DIST
H	SE ENDR	GWT, PA, FUEL	SE MAX ENDR IAS & TIME

```
01♦LBL "FLIGHT"
02 44
03 PSIZE
04 SF 29
05 SF 27
06♦LBL 07
07 0
08 X<>F
09 FIX 0
10 "READY"
11 PROMPT
12 FIX 4
13 RTN
14♦LBL A
15 ADV
16 XEQ 01
17 ADV
18 XEQ 02
19 ADV
20 XEQ 03
21 ADV
22 XEQ 04
23 "DA"
24 GETP
25 XEQ "DA"
26 RCL 10
27 3
28 Y↑X
29 STO 27
30 "E PERF"
31 GETP
32 XEQ "E PERF"
33 "IGE"
34 GETP
35 XEQ "IGE"
36 "OGE"
37 GETP
38 XEQ "OGE"
39 "STALL"
40 GETP
41 100
42 STO 00
43 0
44 STO 01
45 XEQ "STALL"
46 "RNG"
47 GETP
48 XEQ "RNG"
49 "ENDR"
50 GETP
51 XEQ "ENDR"
52 "WTR T/O"
53 GETP
54 XEQ "WTR T/O"
55 "SE RNG"
56 GETP
57 XEQ "SE RNG"
58 "SE ENDR"
59 GETP
60 XEQ "SE ENDR"
61 "PRINT"
62 GETP
63 BEEP
64 FS? 21
65 XEQ "PRINT"
66 GTO 07
67♦LBL a
68 XEQ 02
69 XEQ 01
70 "DA"
71 GETP
72 XEQ "DA"
73 1 E3
74 *
75 TONE 0
76 "DA= "
77 ARCL X
78 "├ FT"
79 PROMPT
80 FIX 3
81 RCL 00
82 SQRT
83 1/X
84 "CNV F= "
85 ARCL X
86 PROMPT
87 GTO 07
88♦LBL B
89 XEQ 02
90 XEQ 01
91 "E PERF"
92 GETP
93 XEQ "E PERF"
94 TONE 0
95 "Q= "
96 ARCL 38
97 "├ %"
98 PROMPT
99 GTO 07
100♦LBL C
101 XEQ 05
102 XEQ 03
103 XEQ 04
104 "IGE"
105 GETP
106 XEQ "IGE"
107 TONE 0
108 "IGE Q= "
109 ARCL 31
110 "├ %"
111 PROMPT
112 GTO 07
113♦LBL c
114 XEQ 05
115 XEQ 03
116 XEQ 04
117 "OGE"
118 GETP
119 XEQ "OGE"
120 TONE 0
121 "OGE Q= "
122 ARCL 32
123 "├ %"
124 PROMPT
125 GTO 07
126♦LBL E
127 XEQ 03
128 XEQ 02
129 "RNG"
130 GETP
131 XEQ "RNG"
132 TONE 0
133 "IAS= "
134 ARCL 34
135 "├ KT"
136 PROMPT
137 XEQ 06
138 RCL 35
139 *
140 TONE 0
141 "RNG= "
142 ARCL X
143 "├ NM"
144 PROMPT
145 GTO 07
146♦LBL e
147 XEQ 03
148 XEQ 02
149 "ENDR"
150 GETP
```

```
151 XEQ "ENDR"
152 TONE 0
153 "IAS= "
154 ARCL 36
155 "⊢ KT"
156 PROMPT
157 XEQ 06
158 RCL 37
159 1/X
160 *
161 FIX 1
162 TONE 0
163 "ENDR= "
164 ARCL X
165 "⊢ HR"
166 PROMPT
167 GTO 07
168♦LBL D
169 XEQ 02
170 XEQ 01
171 "HR ?  "
172 40
173 XTOA
174 "⊢%"
175 41
176 XTOA
177 PROMPT
178 STO 00
179 XEQ 03
180 "∠BANK? "
181 40
182 XTOA
183 "⊢DEG"
184 41
185 XTOA
186 PROMPT
187 STO 01
188 "STALL"
189 GETP
190 XEQ "STALL"
191 TONE 0
192 "IAS= "
193 ARCL 33
194 "⊢ KT"
195 PROMPT
196 GTO 07
197♦LBL F
198 XEQ 01
199 XEQ 03
200 "WTR T/O"
```

```
201 GETP
202 XEQ "WTR T/O"
203 TONE 0
204 "IAS= "
205 ARCL 39
206 "⊢ KT"
207 PROMPT
208 GTO 07
209♦LBL G
210 XEQ 03
211 XEQ 02
212 "SE RNG"
213 GETP
214 XEQ "SE RNG"
215 TONE 0
216 "IAS= "
217 ARCL 40
218 "⊢ KT"
219 PROMPT
220 XEQ 06
221 RCL 41
222 *
223 TONE 0
224 "RNG= "
225 ARCL X
226 "⊢ NM"
227 PROMPT
228 GTO 07
229♦LBL H
230 XEQ 03
231 XEQ 02
232 "SE ENDR"
233 GETP
234 XEQ "SE ENDR"
235 TONE 0
236 "IAS= "
237 ARCL 42
238 "⊢ KT"
239 PROMPT
240 XEQ 06
241 RCL 43
242 1/X
243 *
244 FIX 1
245 TONE 0
246 "ENDR= "
247 ARCL X
248 "⊢ HR"
249 PROMPT
250 GTO 07
```

```
251♦LBL 01
252 "OAT ?  "
253 40
254 XTOA
255 "⊢C"
256 41
257 XTOA
258 PROMPT
259 STO 30
260 15.017
261 XEQ "FILL"
262 RTN
263♦LBL 02
264 "PA ?  "
265 40
266 XTOA
267 "⊢FT"
268 41
269 XTOA
270 PROMPT
271 1 E3
272 /
273 STO 08
274 18.02
275 XEQ "FILL"
276 STO 21
277 RTN
278♦LBL 03
279 "GWT ?  "
280 40
281 XTOA
282 "⊢LB"
283 41
284 XTOA
285 PROMPT
286 1 E3
287 /
288 STO 09
289 22.026
290 XEQ "FILL"
291 RTN
292♦LBL 04
293 "WIND ?  "
294 40
295 XTOA
296 "⊢KT"
297 41
298 XTOA
299 PROMPT
300 STO 11
```

```
301 X↑2
302 STO 28
303 X↑2
304 STO 29
305 RTN
306♦LBL 05
307 "DA ?  "
308 40
309 XTOA
310 "⊢FT"
311 41
312 XTOA
313 PROMPT
314 1 E3
315 /
316 STO 10
317 3
318 Y↑X
319 STO 27
320 RTN
321♦LBL 06
322 "FUEL ?  "
323 40
324 XTOA
325 "⊢LB"
326 41
327 XTOA
328 PROMPT
329 RTN
330♦LBL "FILL"
331 STO 12
332 X<>Y
333 RCL X
334 RCL X
335 RCL X
336 X↑2
337♦LBL 10
338 STO IND 12
339 *
340 ISG 12
341 GTO 10
342 RTN
343♦LBL "FIT"
344 RCL 13
345 3
346 Y↑X
347 RCL X
348 RCL 06
349 *
350 RCL 13
351 X↑2
352 RCL 04
353 *
354 +
355 RCL 13
356 RCL 02
357 *
358 +
359 RCL 00
360 +
361 RCL Y
362 RCL 05
363 *
364 RCL 13
365 X↑2
366 RCL 03
367 *
368 +
369 RCL 13
370 RCL 01
371 *
372 +
373 1
374 +
375 /
376 END
```

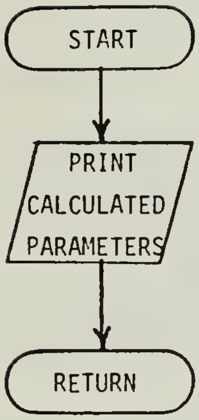
S. PRINT PROGRAM

Program Title: PRINT

Accuracy: (not applicable)

Purpose: This program resides in extended memory and is called by subroutine A to print a hard copy of the output parameters stored in Registers 10 and 31 - 43.

PRINT



```
01♦LBL "PRINT"
02 ADV
03 ADV
04 RCL 10
05 1 E3
06 *
07 "DA  "
08 ARCL X
09 "⊦ FT"
10 PRA
11 ADV
12 31.049
13 "HIGE Q   "
14 XEQ 08
15 "⊦ %"
16 PRA
17 "HOGE Q   "
18 XEQ 08
19 "⊦ %"
20 PRA
21 "BLADE STALL  "
22 XEQ 08
23 "⊦ KT"
24 PRA
25 ADV
26 ADV
27 "MAX RNG"
28 PRA
29 "  IAS   "
30 XEQ 02
31 "⊦ KT"
32 PRA
33 FIX 3
34 "  UNIT RNG  "
35 XEQ 08
36 "⊦ NM/LB"
37 PRA
38 ADV
39 ADV
40 "MAX ENDR"
41 PRA
42 FIX 0
43 "  IAS  "
44 XEQ 08
45 "⊦ KT"
46 PRA
47 "  BURN  "
48 XEQ 08
49 "⊦ LB/HR"
50 PRA
51 ADV
52 ADV
53 ADV
54 ADV
55 "S/E PERFORMANCE"
56 PRA
57 " Q AVL  "
58 XEQ 08
59 "⊦ %"
60 PRA
61 " WTR T/O  "
62 XEQ 08
63 "⊦ KT"
64 PRA
65 ADV
66 " S/E MAX RNG"
67 PRA
68 "  IAS  "
69 XEQ 08
70 "⊦ KT"
71 PRA
72 FIX 3
73 "  UNIT RNG  "
74 XEQ 08
75 "⊦ NM/LB"
76 PRA
77 ADV
78 " S/E MAX ENDR"
79 PRA
80 FIX 0
81 "  IAS  "
82 XEQ 08
83 "⊦ KT"
84 PRA
85 "  BURN  "
86 XEQ 08
87 "⊦ LB/HR"
88 PRA
89 RTN
90♦LBL 08
91 ARCL IND X
92 ISG X
93 ADV
94 RTN
95 .END.
```

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